⊘TRC

12th Floor East Tower
Centre Square
1500 Market Street
Philadelphia, PA 19102

215.246.3447 PHONE
215.665.5748 FAX

www.TRCsolutions.com

Memorandum

Date: February 14, 2013

Ref: CERCLA Docket No. 02-2010-2017; Shieldalloy Metallurgical Corporation Superfund
          Site - Newfield, NJ

To: Sherrel Henry, EPA RPM

cc: Donna Gaffigan, NJDEP; Ed Modica, EPA

Subject: **EPA Procedural Assessment of MNA of Chromium in Groundwater at SMC Site**

This memo summarizes the assessment of Monitored Natural Attenuation (MNA) for the chromium plume at the Shieldalloy Site, in accordance with EPA procedures. TRC's January 2012 In Situ Workplan indicated that TRC would perform this analysis.

The EPA indicates in their October 2007 "*Monitored Natural Attenuation of Inorganic Contaminants in Ground Water*" that MNA assessment must follow the "*tiers***" below, some of which have subcomponents:

Tier I.

1. Demonstration of the plume stability

2. Demonstration of plume attenuation

Tier II.

1. Determination of the mechanism—sorption

2. Determination of mechanism—precipitation

3. Determination of rate of the attenuation processes;

Tier III.

1. Determination of the *capacity* of removal mechanism

2. Determination of the *stability* of removal mechanism

Tier IV.   Implementation of long term performance monitoring plan.

This memo summarizes the Tier I, II, and III MNA assessment. Tier IV, MNA long-term performance monitoring plan will be addressed under separate cover. Further, some predictive MNA modeling, based on EPA models, will also be provided under separate cover.

Tier I: Demonstration of Plume Stability and Attenuation Feasibility

Tier 1.1 Demonstration of Plume Stability

EPA Guidance (EPA 2007a) indicates that the first step (Tier I) of the assessment of MNA viability is to determine that the ground-water plume is stable or shrinking (not expanding). Assessment of plume

stability was performed via a statistical analysis of at least 8 quarters of data (ITRC, 2010). As required by EPA procedure, plume stability was demonstrated using the Mann-Kendall Statistical Test for Trend.

TRC elected to study the area of the plume between the Car Wash and the Farm Parcel (see Figure 1) because this area of the plume, during the period of time selected, is outside of the influence of pumping (and pre-dates injections), and is therefore indicative of MNA processes. Four monitoring wells (i.e., SC-4S, SC-4D, SC-10D, and SC-28D) exist in the study area and have good data sets of chromium over time. As required by EPA, for each well, the most recent eight rounds of data were evaluated for each individual quarter (January, April, July, and October) to address potential seasonal influences in the data. The results of the Mann-Kendall analysis (Attachment 1) indicate the following:

- SC-4D: Decreasing trend (at >95% confidence level);
- SC-10D: Stable to Decreasing trend (at 90% to >95% confidence level);
- SC-28D: Stable to Decreasing trend (at 80% to >95% confidence level); and
- SC-4S: Stable (at 80% confidence level).

It is concluded that the plume in the study area is **stable or shrinking (decreasing trend) indicating that chromium is attenuating**.

Other monitoring wells between the Car Wash and Farm Parcel (i.e., wells SC-18S, SC-18D, SC-19S, SC-19D, SC-21S and SC-21D), could not support statistical analysis of the data since total and/or hexavalent chromium were detected only occasionally at low concentrations. The four wells analyzed above provide better data assessment of plume stability.

Tier 1.2 Demonstration of Attenuation Feasibility

EPA Guidance (EPA 2007a) also indicates that Tier I of the MNA assessment should provide evidence that aquifer conditions are conducive to attenuation of contaminants. Potential mechanisms that can remove chromium from groundwater are reduction by ferrous iron, co-precipitation, and sorption onto iron oxide (ferric oxide – Fe_2O_3) and hydroxide complexes, and clay minerals. TRC has studied these mechanisms, as discussed below, and has found that the primary attenuation processes are sorption onto iron (and potentially clay minerals) and reduction/precipitation reactions with native iron. The site-specific assessment confirmed that **reductants and sorbents that facilitate attenuation of chromium are present in the aquifer**.

EPA studies show that hexavalent forms of chromium can be reduced by ferrous iron to sparingly soluble trivalent chromium hydroxide and that chromium can sorb onto iron oxides in aquifer soils (EPA, 2007b). TRC's analyses of Site aquifer soils show that iron is abundant in aquifer soils (concentrations ranging from approximately 2,000 milligrams per kilogram (mg/kg) to 10,000 mg/kg) as shown on Table 1. Furthermore, Site studies indicate that a substantial amount of the aquifer soil iron is in the ferrous iron (Fe^{2+}) and iron oxide (Fe_2O_3) forms – See Attachment 2. Soil profiling and past mineralogical studies (TRC, 2008; TRC 2012) confirmed the presence of ferrous iron, sulfur and clay minerals (e.g., pyrite, sulfite, illite, and kaolinite) within the upper and lower plume zones, which demonstrates that the forms of iron and minerals responsible for attenuation of chromium are present in the aquifer including the area between the Farm Parcel and Facility.

A more detailed assessment of the attenuation mechanisms is discussed Tier II assessment below.

Tier II: Determination of the *Mechanism and Rate* of the Attenuation Processes

While it is clear from the Tier I analysis that the plume is stable (or decreasing/shrinking), and that iron and clay minerals that facilitate attenuation of chromium exist in aquifer soils under the Site, EPA Tier II requires the determination of the MNA mechanism and rate. TRC considered two lines of evidence to understand the mechanism of MNA and a third line of evidence to estimate the rate of MNA. These lines of evidence include:

1. Laboratory treatability test results;

2. Correlations of soil and co-located groundwater samples; and

3. Groundwater concentration trends along groundwater flow paths.

These lines of evidence are described below.

Tier II.1 MNA Mechanism: Reduction/Precipitation - Laboratory Treatability Tests

TRC conducted batch and column treatability studies (TRC, 2011) as part of the in situ pilot program. These treatability studies specifically measured attenuation in control (un-amended) samples of aquifer soils and groundwater with representative chromium concentrations, which reflect "natural" conditions within the chromium plumes in the upper and lower zones of the aquifer. Each of the natural (control) samples evaluated during the treatability studies exhibited significant reductions (up to 90 percent or more) of total and hexavalent chromium in groundwater. Attachment 3 presents the results of treatability tests, which clearly demonstrate the attenuation of hexavalent and total chromium concentrations in untreated control samples.

The treatability test results, including the sustained removal of chromium from groundwater and the confirmed presence of iron in soil in forms that have been verified in numerous scientific studies to attenuate chromium, demonstrate that **chromium is attenuated by naturally occurring iron minerals in site soil**.

Tier II.2 MNA Mechanism: Sorption - Soil and Groundwater Concentrations Correlation

As another line of evidence to understand the adsorption and attenuation capabilities of aquifer Site soils as part of Tier II, TRC compared chromium concentrations in groundwater to co-located soil concentrations of chromium. If chromium is adsorbing to aquifer soils, a positive correlation between chromium concentrations in the soil and groundwater should exist. This correlation (graph) describes the sorption process and represents the contaminant distribution between the liquid and solid phases at equilibrium. The slope of the graph yields the bulk average distribution coefficient. TRC studied groundwater/soil correlations for 22 locations at various depths within the chromium plumes.

Plots showing the correlation between chromium concentrations in soil and groundwater in the upper and lower aquifer zones along with the data used to develop these plots are provided in Attachment 4.

Both plots show that a positive correlation generally exists between chromium concentrations in soil and groundwater within the upper and lower plumes, respectively.

Using co-located soil and groundwater concentrations from representative locations, the distribution (sorption) coefficient (K_d) was estimated to range from 0.3 liters per kilogram (L/Kg) to 908 L/Kg within the upper plume zone with a geomean of approximately 15 L/Kg, and from 1.2 L/Kg to 221 L/Kg with a geomean of 21 L/Kg for the deep plume zone. The higher sorption coefficient for the lower plume reflects the higher clay and iron content. TRC used these estimates to evaluate the retardation the plume transport due to Sorption. The Retardation Factor (R_d) was estimated to range from 2.4 to 3,632 with a geomean of approximately 69 within the upper plume, and from 6.3 to 994 with a geomean of approximately 97 for the lower plume. These data indicate that the average chromium transport rate by advection is 69 times slower than the average groundwater velocity within the upper zone and 97 times slower than the average groundwater velocity the lower zone. Calculations are presented in Attachment 4.

The above analysis indicates **adsorption is a key MNA mechanism at the Site**.

Tier II.3 MNA Bulk Attenuation Rate - Groundwater Concentration Trends Along Groundwater Flow Paths

Tier II requires that the MNA _rate_ be assessed. The EPA indicates (EPA 2002) that a good way to analyze the MNA rate at a Site such as the Shieldalloy Site, is to evaluate changes in contaminant concentrations along groundwater flow paths. More specifically, the EPA indicates that fitting a straight line on a logarithmic plot of concentrations along a flow line (i.e., concentrations versus location/distance) will indicate if concentrations trend downward (e.g., decrease) along that flow path. More so, the slope of that line combined with the groundwater seepage velocity will provide the rate of decrease (which the EPA calls the site-specific bulk attenuation factor).

Similar to Tier I analysis of plume stability, the Tier II analysis considers the area between the Car Wash and the Farm Parcel, to estimate the MNA "bulk attenuation rate". TRC studied two series of wells (along a primary flow path) in the upper aquifer, and two series of wells (along a primary flow path) in the lower aquifer, as shown on Figure 1. The analysis indicates that chromium concentrations (prior to CPS injections) decline along each of the four flow paths studied. Data and the statistical analysis are provided in Attachment 5. Accordingly, site-specific bulk attenuation rates were calculated to range from 0.004 day^{-1} to 0.023 day^{-1} (a half-life of 0.5 year to 0.1 year) for the upper plume, and from 0.0005 day^{-1} to 0.0025 day^{-1} (a half-life of 4 years to 0.8 year) for the lower plume. The calculations used to derive these rates/half-lives are included with Attachment 5.

As an additional verification, TRC compared these MNA rates to the rates found during the treatability testing and found that the rates indicated above are consistent with the treatability testing results of "natural" conditions, which further substantiates the analysis.

This analysis suitably finds the mechanism and rate of MNA at the Site, and supports the viability of MNA.

Tier III. Determination of the _Capacity_ and the _Stability_ of MNA Mechanism

Tier III.1 Assessment of Aquifer Natural Attenuation Capacity

As part of Tier II, TRC's analysis demonstrated that reduction/precipitation and sorption are key MNA mechanisms. Tier III requires that the aquifer's "natural attenuation capacity" be evaluated. Capacity, in this case, was estimated using two techniques:

- Mass balance from the treatability testing of untreated soil and groundwater samples obtained from the upper and lower plumes (TRC, 2011); and

- Mineralogy and natural reactive iron content.

Mass Balance: As indicated in Attachment 6, soils from the upper plume zone used as controls in the in situ lab studies attenuated approximately 0.2 grams of total chromium per kilogram of soil, which is equivalent to approximately 8 grams of chromium per cubic foot of soil (g-Cr/ft^3-soil). Similarly, soils from the lower plume zone attenuated approximately 0.3 grams of total chromium per kilogram of soil, which is equivalent to a bulk attenuation capacity of approximately 14 g-Cr/ft^3-soil. For comparison, the mass of dissolved chromium in a unit volume of the plume between the Facility boundary and the Car Wash using the highest concentrations of chromium detected in this area was calculated to be 4 grams (upper plume) and 13 grams of chromium (lower plume), respectively, which are lower than the estimated natural attenuation capacity. The estimates yield a safety factor (ratio of bulk natural attenuation capacity divided over chromium mass in unit volume of the plume) in the range of about 2 for the upper plume and 1.1 for the lower plume.

Reactive Ferrous Iron Content: The bulk attenuation capacity was also estimated in Attachment 6 using a simplified stoichiometric relationship between native ferrous iron content in soil from the deep aquifer (the principal MNA driver at the Site) to chromium concentrations. Stoichiometrically, 3.2 grams of ferrous iron can reduce 1 gram hexavalent chromium. The amount of ferrous iron in one kilogram of soil based upon mineralogical analysis of soil from the deep aquifer was estimated to range from approximately 4 grams per kilogram (g/kg) to 20 g/kg. By comparison, the dissolved chromium mass contained in a kilogram of soil using maximum concentrations of chromium detected in deep groundwater between the Facility and Car Wash was about 0.0005 g/kg. Thus, based upon stoichiometry, soils in the deep aquifer contain sufficient ferrous iron to attenuate chromium present in groundwater between the Facility and Farm Parcel Injection Areas. These estimates yield a safety factor in the range of 2,400 to 12,800 which should be adequate to address the demands for chromium reduction/precipitation and competing geochemical reactions in the aquifer.

These calculations demonstrate that **the aquifer has adequate capacity to attenuate the remaining dissolved chromium**.

Tier II.2 Assessment of MNA Stability

Also as part of Tier III assessment, the STABILITY of the removal mechanism must be assessed. Stability is evaluated based on:

- Stability during the treatability studies; and

- Aquifer geochemistry.

Treatability Studies: The results of the control columns of the treatability study using un-amended soil and groundwater samples (TRC, 2011), which lasted more than 60 days, demonstrate the stability of the natural attenuation of chromium. During the treatability study, there was no reversal observed following the reduction of chromium concentrations due to reduction by ferrous iron and/or precipitation even after passing more than 200 pore volumes of contaminated groundwater through the soil columns and increasing the flow rates by up to 10 times. Similarly, batch tests on un-amended, control soil and groundwater samples from the plume zones which lasted up to 70 days confirmed the natural attenuation of chromium was stable with no reversal, including those samples that were subjected to aggressive aeration (due to shaking static batch samples and substantially increasing flow rates under dynamic flow-through conditions).

Aquifer geochemistry: As indicated above, the primary MNA process is reduction/precipitation, whereby hexavalent chromium is reduced to the less soluble chromium (trivalent) hydroxide and iron-chromium complexes, which readily precipitate out of solution. EPA guidance documents (EPA, 2007b; EPA, 1994) indicate that the process that has been verified to reverse this attenuation reaction (i.e., re-oxidization of the less soluble trivalent to the mobile hexavalent chromium) is the presence of manganese oxides at high concentrations under oxidizing environment.   The previous site investigations and the treatability studies clearly confirmed that manganese concentrations are negligible, often not-detected, and that the reduction/precipitation mechanism is stable (TRC, 2011).

As shown on the Eh-pH diagram for chromium presented in Attachment 2, once hexavalent chromium is reduced to the sparingly soluble chromium hydroxide or chromium-iron complexes, natural conditions make it untenable for the chromium state to reverse and concentrations to rebound. Specifically, redox potential and pH levels (as shown for example wells SC-4S/D, SC-10S/D, SC-28D, SC-38I, SC-41D, SC-42D, Layne, A, B, and W-9 prior to CPS injections) demonstrate that ambient geochemical conditions in the shallow and deep aquifer zones favor insoluble and stable trivalent chromium forms over the more soluble hexavalent chromate (CrO_4^{2-}) ion. These data (specifically redox and pH data from wells Layne, A, B, and W-9 located upgradient of the Car Wash) indicate that once hexavalent chromium has been reduced to this trivalent form, a reversal to the hexavalent chromate ion is not likely to occur as a result of groundwater flow onto the Car Wash Property and Farm Parcel from upgradient areas. This indicates that the **stability of chromium removal is suitable for MNA**.

To further assess the stability, TRC has compared chromium concentrations in groundwater before and after recent injections, because, as a result of these injections, MAJOR attenuation has occurred (making this a conservative case to study). Post injection results, shown in Figure 2 shows that there has been no reversal of chromium concentrations (_i.e.,_ very good stability).

Summary and Conclusions

In summary, the data presented herein demonstrate the following:

1. Tier I—chromium concentrations in groundwater are decreasing or stable over time.

2. Tier II—native iron in site soils is attenuating chromium through chemical reduction to sparingly soluble chromium hydroxide, co-precipitation with stable iron complexes and sorption onto iron oxides/complexes in the aquifer.

3. Tier II—the natural attenuation rate has been ascertained, and is reasonable.

4. Tier III—the capacity of the natural attenuation mechanism is sufficient and the stability of the removal mechanism is strong.

TRC performed the EPA MNA assessment and has found that each of the three Tiers is satisfied at the SMC Site. ***MNA is viable and appropriate to SMC***.

TRC will submit, under separate cover, the Tier IV (long term monitoring plan). TRC will also submit, under separate cover, some predictive MNA modeling, based on EPA models.

References

Interstate Technical Regulatory Council, 2010. *A Decision Framework for Applying Monitored Natural Attenuation Processes for Metals and Radionuclides in Groundwater*. December 2010.

TRC, 2008. *Permit-By-Rule In Situ Chemical Reduction Application* dated February 1, 2008.

TRC, 2011. *Supplemental Treatability Study" and it was reported in the "In Situ Remediation Pilot Test Report and Expanded In Situ Remediation Pilot Program Workplan* dated February 18, 2011

TRC, 2012. *OU1 Facility Expanded ISR Pilot Program Progress Report & Phase 2 Farm Parcel ISR Pilot Study Workplan* dated February 17, 2012.

US Environmental Protection Agency, 1994. *Natural Attenuation of Hexavalent Chromium in Groundwater and Soils*. EPA Groundwater Issue. October, 1994. EPA/540/5-94/505.

US Environmental Protection Agency, 2002. *Calculation and Use of First-order Rate Constants for Natural Attenuation*. EPA Groundwater Issue. November 2002. EPA/540/S-02/500.

US Environmental Protection Agency, 2007a. *Monitored Natural Attenuation of Inorganic Contaminants in Groundwater. Volume 1 Technical Basis*. EPA/600/R-07/139. October 2007.

United States Environmental Protection Agency, 2007b. *Monitored Natural Attenuation of Inorganic Contaminants in Groundwater. Volume 2 Assessment of Non Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate and Selenium*. EPA/600/R-07/139. October 2007.

Table 1
Soil and Groundwater Summary Data for MNA Evaluation
Shieldalloy Metallurgical Corporation
Newfield, NJ

FACILITY

Matrix	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW
Sample Name	STSB-2	A	STSB-2	W9	STSB-2	--	STSB-2	B	STSB-2	LAYNE	TS MWH-4	MWH-4
Sample Date	12/8/2009	10/21/2009	12/8/2009	4/1/2010	12/8/2009		12/7/2009	10/21/2009	12/7/2009	4/1/2009	1/16/2007	1/17/2007
Sample Interval	105-130	114-124	105-130	110-130	55-110		35-50	36-46	35-50	43-48	122.5-123	119-129
Units	mg/kg	ug/L	mg/kg	ug/L	mg/kg		mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L
Cr	32.4	ND	32.4	4,350	11.0		6.25	205	6.1	1090	0	4
Cr(VI)	20.4	ND	20.4	4,200	19.3		ND	ND	ND	910	pH	231
Fe	5950	NA	5950	NA	4030		4990	NA	4990	NA	NA	227
Dissolved Fe	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA
pH	6.9	8.47	6.9	NA	8.07		7.74	NA	7.74	NA	Fe	70
ORP	NA	NA	NA	NA	NA		NA	NA	NA	NA	Mn	*
TCE	NA	ND	NA	NA	NA		NA	0.26	NA	NA	NA	

FACILITY

Matrix	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW
Sample Name	VP-1(100-105)	VP-1(104-109)	VP-1(90-95)	VP-1(90-95)	VP-3(110-115)	VP-3(110-115)	VP-3(90-95)	VP-3(90-95)	VP-3(75-80)	VP-3(75-80)	VP-3(55-60)	VP-3(55-60)	VP-3(35-40)	VP-3(35-40)	VP-3(20-25)	VP-3(20-25)	VP-4(20-25)	VP-4(20-25)
Sample Date	7/30/2010	7/29/2010	7/28/2010	7/29/2010	8/4/2010	8/2/2010	8/4/2010	8/4/2010	8/4/2010	8/4/2010	8/4/2010	8/4/2010	8/4/2010	8/4/2010	8/4/2010	8/4/2010	8/5/2010	8/5/2010
Sample Interval	100-105	104-109	90-95	90-95	110-115	110-115	90-95	90-95	75-80	75-80	55-60	55-60	35-40	35-40	20-25	20-25	20-25	20-25
Units	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L
Cr	4.8	180	4.9	14.3	6	163	3.4	28.9	4.5	95.4	2.9	97.2	14.3	1740	5.2	ND	134	ND
Cr(VI)	ND	48	ND	ND	0.63	78	ND	ND	0.51	22	ND	ND	2.6	ND	ND	ND	7.9	0
Fe	4790	43000	4800	5510	7080	16000	4770	11500	1990	36700	4440	44000	3840	121000	6880	2180	3570	0
Dissolved Fe	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
pH	7.03	5.64	7.02	5.31	7.38	5.81	7.08	4.58	7.56	4.64	5.81	4.41	6.48	5.27	8.11	6.55	7.45	0.00
ORP	403	-51.7	404	12.1	392	87.8	407	175.5	418	76.8	515	155.9	477	-3.6	381	-226.7	411	0.0
TCE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

FARM PARCEL

Matrix	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW
Sample Name	SC-2I	SC-2I	STSB-1	IW2P110-120	STSB-1	SC-2D(R	STSB-1	IW2P95-105	STSB-1	IW2P80-90	STSB-1	IW2	TS SC2D(R	SC-2D(R	SC-42D	SC-42D	SC-42D	IW-1
Sample Date	10/5/2011	10/1/2011	10/24/2009	1/25/2010	10/24/2009	10/21/2009	10/24/2009	1/25/2010	10/23/2009	1/26/2010	10/23/2009	10/21/2009	1/23/2007	1/16/2007	10/3/2011	10/26/2011	10/3/2011	4/28/2011
Sample Interval	45-65	40-70	110-120	110-120	100-120	106-116	90-110	95-105	80-90	80-90	40-70	40-70	106.5-107	106-116	105-125	110-120	45-65	32-62
Units	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L
Cr	3.05	2280	11.2	11	24.35	12,000	24.35	12,500	7.3	21,300	10.2	4,810	23.5	19770	4.7	ND	3.5	ND
Cr(VI)	0.5	2600	ND	ND	24.8	11,600	24.8	12,900	ND	21,500	ND	4,400	23.1	24600	0.665	10	ND	16
Fe	2167.5	NA	9840	3570	5235	NA	5235	2140	3850	17600	2983.3	NA	NA	<100	5268	2590	4318	NA
Dissolved Fe	NA	NA	NA	381	NA	NA	NA	ND	NA	ND	NA	NA	NA	NA	NA	1760	NA	NA
pH	7.84	8.82	5.94	4.93	6.12	5.64	6.12	6.04	6.1	5.38	7.73	5.89	6.58	5.9	5.25	6.82	6.19	6.23
ORP	341.5	NA	339	95	404	NA	404	125	395	232	350	NA	NA	167	373	0.3	391	257
TCE	NA	NA	NA	NA	NA	3.2	NA	NA	NA	NA	NA	16	ND	NA	NA	NA	NA	NA

CAR WASH

Matrix	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW
Sample Name	SC-41D	SC-41D	SC-41D	SC-6S	SC-41D	RW-6S	SC-41D	SC-38I
Sample Date	10/7/2011	10/26/2011	10/7/2011	11/2/2011	10/7/2011	10/31/2011	10/7/2011	10/31/2011
Sample Interval	110-120	110-120	45-65	45-65	45-65	55-75	45-65	45-55
Units	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L	mg/kg	ug/L
Cr	11.8	40.8	3	ND	3	643	3	49.9
Cr(VI)	4.3	13	ND	ND	ND	580	ND	45
Fe	4710	1440	3248	NA	3248	NA	3248	NA
Dissolved Fe	NA	ND	NA	NA	NA	NA	NA	NA
pH	7.6	11.37	5.7	6.39	5.7	7.9	5.7	6.65
ORP	332	160	399	191	399	228	399	304
TCE	NA	NA	NA	1.4	NA	2.3	NA	ND

Site Plan — Shieldalloy Metallurgical Corporation, Newfield, New Jersey
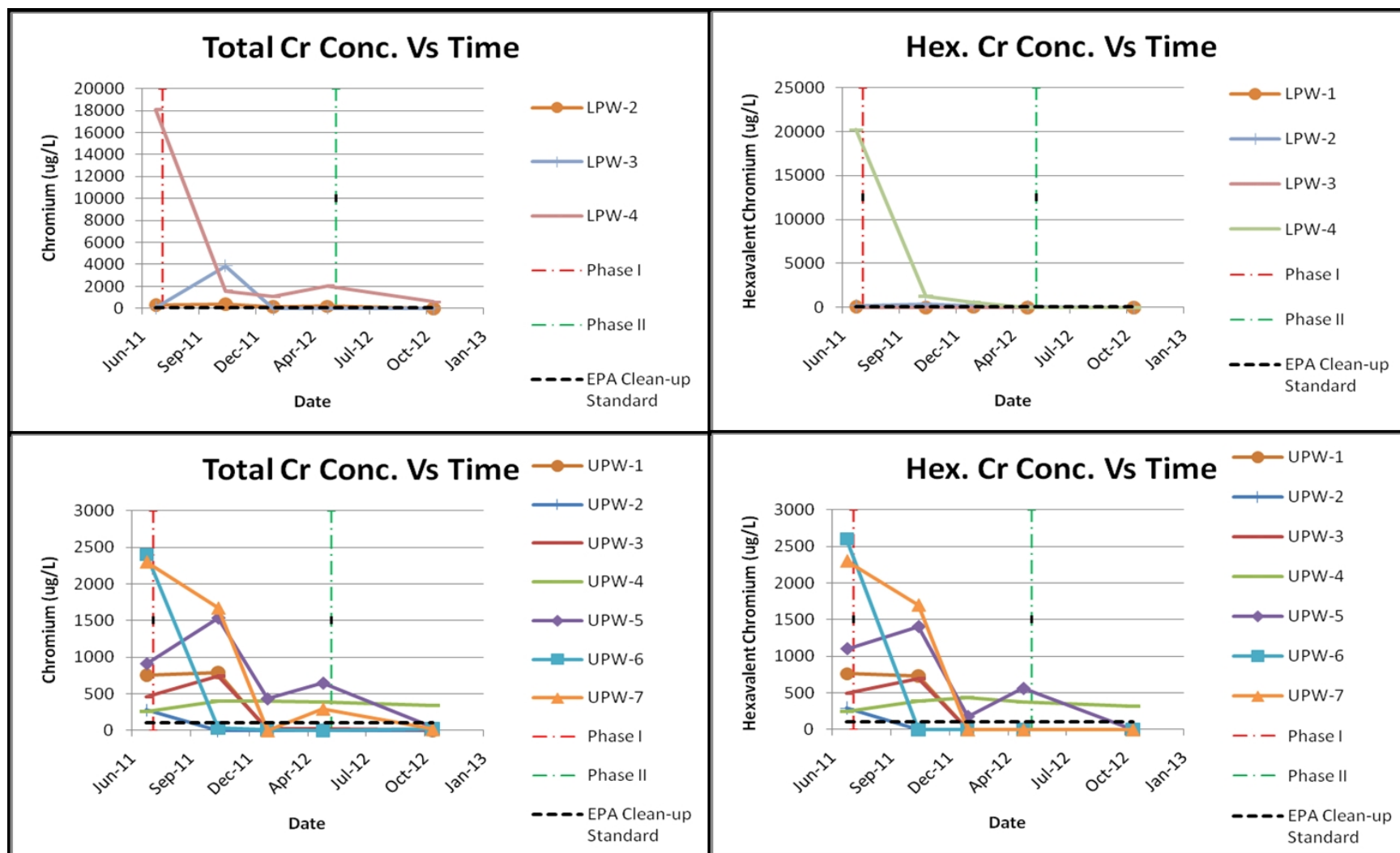
FIGURE 2 – STABILITY OF TOTAL AND HEXAVALENT CHROMIUM REDUCTIONS IN UPPER AND LOWER PLUME FOLLOWING CPS INJECTION AT FACILITY

ATTACHMENT 1
MANN-KENDALL TREND ANALYSES

Attachment 1
Description of Mann-Kendall Statistical Test for Trend

In the Mann-Kendall Test, the concentration of a contaminant detected during each quarterly monitoring event at a specific monitoring well is compared to concentrations detected at the well during subsequent quarterly monitoring events. If the concentration of a subsequent monitoring event is greater than the value from the earlier time, a value of "+1" is assigned to the comparison of paired concentrations. Alternatively, if the value of a subsequent observation is less than the value from the earlier time, a value of "-1" is assigned. When two measurements are identical, the comparison is assigned 0. After scoring the entire data set for a well, the assigned values are summed to determine the Mann-Kendall S-statistic. The absolute value of the S-statistic is then compared to the theoretical distribution of S developed by Mann-Kendall for different probability levels for which a value of S would indicate no trend. If the calculated value of S is positive and exceeds the theoretical S value, an increasing trend exists. Alternatively, if the calculated value is negative and its absolute value is greater than the theoretical value of S, a decreasing trend exists. S values near "0" indicate a lack of a trend. In this case, a calculation of the coefficient of variation (CV) is performed to assess scatter in the data, such that when the CV is equal to or less than unity, concentrations in the well are stable. Additional information regarding the Mann-Kendall is presented by Gilbert in Statistical Methods for Environmental Pollution Monitoring, Van Nostrand Reinhold, New York, 1987.

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-28D
	Compound ->	$Cr_{(total)}$	Cr^{6+}				
		Concentration	Concentration	Concentration	Concentration	Concentration	Concentration
Event Number	Sampling Date (most recent last)	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;
1	Jan-03	319	305				
2	Jan-04	205	192				
3	Jan-05	140	140				
4	Jan-06	105	99				
5	Jan-07	185	160				
6	Jan-08	129	70				
7	Jan-09	132	40				
8	Jan-10	174	150				
9							
10							
	Mann Kendall Statistic (S) =	-10.0	-16.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	173.63	144.50	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	67.413	81.808	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.388	0.566	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		DECREASING	DECREASING	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		No Trend	DECREASING	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		No Trend	DECREASING	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at				n<4	n<4	n<4	n<4
80% Confidence Level		NA	NA	n<4	n<4	n<4	n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-28D
	Compound ->	Cr_{Total}	Cr^{6+}				
		Concentration	Concentration	Concentration	Concentration	Concentration	Concentration
Event Number	Sampling Date (most recent last)	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;
1	Apr-04	170	165				
2	Apr-05	147	130				
3	Apr-06	140	130				
4	Apr-07	165	170				
5	Apr-08	175	160				
6	Apr-09	138	100				
7	Apr-10	178	150				
8	Apr-11	154	120				
9							
10							
	Mann Kendall Statistic (S) =	2.0	-9.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	158.38	140.63	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	15.775	24.559	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.100	0.175	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		No Trend	DECREASING	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		CV <= 1 STABLE	NA	n<4 n<4	n<4 n<4	n<4 n<4	n<4 n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy					BRRTS No. =		Well Number =	SC-28D
	Compound ->	Cr_{Total}	Cr^{6+}					
Event Number	Sampling Date (most recent last)	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;
1	Jul-02	318	319				
2	Jul-03	216	206				
3	Jul-04	156	142				
4	Jul-05	96	94				
5	Jul-06	198	190				
6	Jul-07	150	140				
7	Jul-08	206	180				
8	Jul-09	167	160				
9							
10							
	Mann Kendall Statistic (S) =	-8.0	-10.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	188.39	178.88	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	64.875	66.469	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.344	0.372	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		DECREASING	DECREASING	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		NA	NA	n<4 n<4	n<4 n<4	n<4 n<4	n<4 n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =			

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-28D
	Compound ->	Cr_{total}	Cr^{6+}				
Event Number	Sampling Date (most recent last)	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;
1	Oct-05	101	51				
2	Oct-06	203	190				
3	Oct-07	138	130				
4	Oct-08	154	120				
5	Oct-09	177	150				
6	Oct-10	150	140				
7	Oct-11	117	92				
8	Oct-12	134	130				
9							
10							
	Mann Kendall Statistic (S) =	-4.0	-1.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	146.75	125.38	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	32.425	40.907	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.221	0.326	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		CV <= 1 STABLE	CV <= 1 STABLE	n<4 n<4	n<4 n<4	n<4 n<4	n<4 n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

S:\ENV RMD Projects\Shield Alloy\Car wash MNA\Attachment 1_MNA_Mann-Kendall without anomalies.xls/SC28D October

TRC Solutions

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-4D
	Compound ->	Cr_{total}	Cr^{6+}				
Event Number	Sampling Date (most recent last)	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;
1	Apr-02	13,100	13,600				
2	Apr-03	12,800	12,600				
3	Apr-04	15,900	13,700				
4	Apr-05	10,200	11,600				
5	Apr-06	9,960	10,200				
6	Apr-07	8,890	9,100				
7	Apr-08	8,350	8,000				
8	May-12	2,110	1,900				
9							
10							
	Mann Kendall Statistic (S) =	-24.0	-24.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	10163.75	10087.50	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	4110.853	3898.145	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.404	0.386	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		DECREASING	DECREASING	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		DECREASING	DECREASING	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		DECREASING	DECREASING	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		NA	NA	n<4 n<4	n<4 n<4	n<4 n<4	n<4 n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

TRC Solutions

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-4S
	Compound ->	Cr_{total}	Cr^{6+}				
Event Number	Sampling Date (most recent last)	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;
1	Apr-04	260	36				
2	Apr-05	102	29				
3	Apr-06	129	30				
4	Apr-07	89	20				
5	Apr-08	146	37				
6	Apr-09	135	19				
7	Apr-10	154	52				
8	Apr-11	90	29				
9							
10							
	Mann Kendall Statistic (S) =	-2.0	-1.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	138.13	31.50	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	55.155	10.515	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.399	0.334	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		CV <= 1 STABLE	CV <= 1 STABLE	n<4 n<4	n<4 n<4	n<4 n<4	n<4 n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

Page 6 of 10

TRC Solutions   S:\ENV RMD Projects\Shield Alloy\Car wash MNA\Attachment 1_MNA_Mann-Kendall without anomalies.xls/SC4s Cr April

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-10D
	Compound ->	Cr_{total}	Cr^{6+}				
Event Number	Sampling Date (most recent last)	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;
1	Jan-03	1850	1200				
2	Jan-04	1300	487				
3	Jan-05	696	370				
4	Jan-06	1570	1600				
5	Jan-07	895	730				
6	Jan-08	859	820				
7	Jan-09	606	440				
8	Jan-10	3,180	3,200				
9							
10							
	Mann Kendall Statistic (S) =	-6.0	4.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	1369.50	1105.88	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	851.563	943.345	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.622	0.853	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		CV <= 1 **STABLE**	CV <= 1 **STABLE**	n<4	n<4	n<4	n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

TRC Solutions

Page 7 of 10
S:\ENV RMD Projects\Shield Alloy\Car wash MNA\Attachment 1_MNA_Mann-Kendall without anomalies.xls/SC10D Cr January

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-10D

| | Compound -> | Cr_{total} | Cr^{6+} | | | | |
Event Number	Sampling Date (most recent last)	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;
1	Apr-03	2810	2,900				
2	Apr-04	1650	1,240				
3	Apr-05	999	1,000				
4	Apr-06	1860	1,800				
5	Apr-07	1020	1,200				
6	Apr-08	806	760				
7	Apr-09	713	620				
8	Apr-11	400	330				
9							
10							
	Mann Kendall Statistic (S) =	-22.0	-22.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	1282.25	1231.25	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	782.056	808.057	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.610	0.656	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		DECREASING	DECREASING	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		DECREASING	DECREASING	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		DECREASING	DECREASING	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		NA	NA	n<4	n<4	n<4	n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

Mann-Kendall Statistical Test
Revised to Evaluate Trend at ≥ 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-10D
	Compound ->	Cr_{total}	Cr^{6+}				
		Concentration	Concentration	Concentration	Concentration	Concentration	Concentration
Event Number	Sampling Date (most recent last)	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;	(blank if no data;
1	Jul-02	603	84				
2	Jul-03	2,220	2,000				
3	Jul-04	1,210	1,140				
4	Jul-05	1,070	1,100				
5	Jul-06	1,050	950				
6	Jul-07	5,570	5,700				
7	Jul-08	647	390				
8	Jul-09	3,800	4,100				
9							
10							
	Mann Kendall Statistic (S) =	4.0	4.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	2021.25	1933.00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	1780.987	1963.210	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.881	1.016	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		No Trend	No Trend	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		CV <= 1 STABLE	CV > 1 NON-STABLE	n<4	n<4	n<4	n<4
				n<4	n<4	n<4	n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

Mann-Kendall Statistical Test
Evaluate Trend at 80 to 95% Confidence Level

Instructions: Do not change formulas or other information in cells with a blue background, only cells with a yellow background are used for data entry. To use the spreadsheet, provide at least four rounds and not more than ten rounds of data that is not seasonally affected. Use consistent units. The spreadsheet contains several error checks, and a data entry error may cause "DATA ERR" or "DATE ERR" to be displayed. Dates that are not consecutive will show an error message and will not display the test results. The spreadsheet tests the data for both increasing and decreasing trends at 80 percent, 90 percent and 95 percent confidence levels.

Site Name = Shield Alloy				BRRTS No. =		Well Number =	SC-10D
	Compound ->	Cr_{total}	Cr^{6+}				
Event Number	Sampling Date (most recent last)	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;	Concentration (blank if no data;
1	Oct-03	1770	677				
2	Oct-05	1230	910				
3	Oct-06	1080	830				
4	Oct-07	1350	1200				
5	Oct-08	557	460				
6	Oct-09	3180	620				
7	Oct-10	478	370				
8	Oct-11	345	190				
9							
10							
	Mann Kendall Statistic (S) =	-14.0	-16.0	0.0	0.0	0.0	0.0
	Number of Rounds (n) =	8	8	0	0	0	0
	Average =	1248.75	657.13	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Standard Deviation =	920.392	322.894	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	Coefficient of Variation(CV)=	0.737	0.491	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Error Check, Blank if No Errors Detected				n<4	n<4	n<4	n<4
Trend ≥ 80% Confidence Level		**DECREASING**	**DECREASING**	n<4	n<4	n<4	n<4
Trend ≥ 90% Confidence Level		**DECREASING**	**DECREASING**	n<4	n<4	n<4	n<4
Trend ≥ 95% Confidence Level		No Trend	**DECREASING**	n<4	n<4	n<4	n<4
Stability Test, If No Trend Exists at 80% Confidence Level		NA	NA	n<4 n<4	n<4 n<4	n<4 n<4	n<4 n<4
Data Entry By = JSH			Date = 22-Jan-13		Checked By =		

ATTACHMENT 2
pH-Eh DIAGRAMS SHOWING DATA FROM
MONITORING WELLS BETWEEN FACILITY AND FARM PARCEL

Attachment 2
Summary of Groundwater Eh and pH data
at Monitoring Wells Located between Farm Parcel and Facility
Shield Alloy Site
Newfield, New Jersey

Monitoring Well	Monitoring Event	Field Eh	$Eh_{H.E.}$ (mV)	pH Std Units)	Temperature ($^{\circ}$C)
SC-4S	May-12	360	573	5.1	14.58
SC-4D	May-12	232	445	5.95	14.35
SC-6S	Nov-11	205	419	6.44	13.38
SC-6D	Oct-11	328	542	4.2	13.64
SC-10S	May-12	337	551	6.67	14.07
SC-10D	May-12	266	480	7.54	13.47
SC-38I	Oct-11	303	516	6.65	15.56
SC-41D	May-12	90.6	304	9.21	13.95
SC-43D	May-12	-75	138	6.65	14.62

Notes:

1. Monitoring event respresents measurement from most recent sampling event.
2. Eh values represent adjustment of field measured values using Ag/AgCL KCL electrode to hydrogen reference electrode that is the reference standardfor Eh-pH diagrams. Correction is made as follows:

    $Eh_{H.E.} = E + 206$ mV $- 0.7(T-25)$

    $Eh_{H.E.}$ = Eh reference to hydrogen electrode, mV

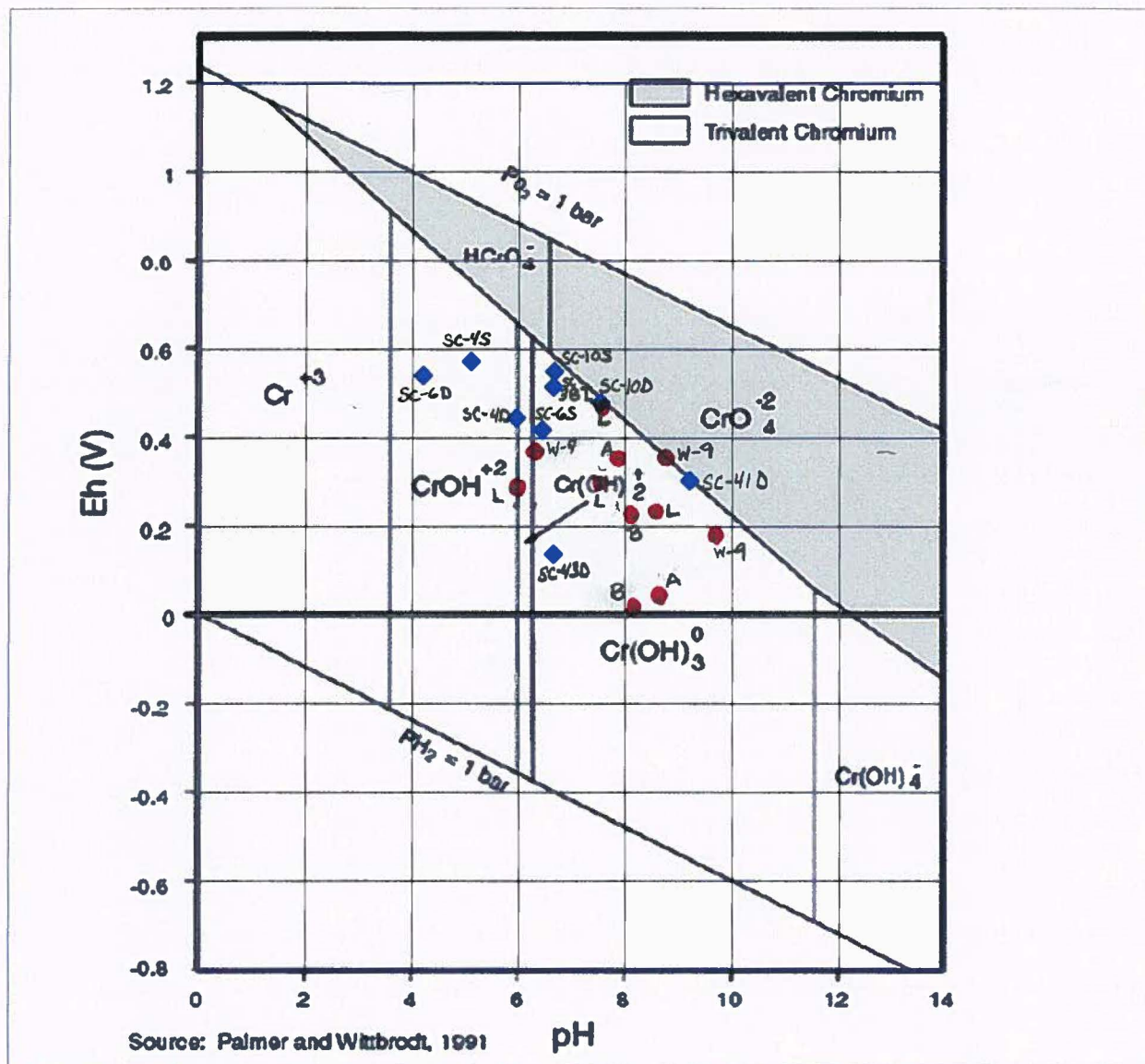   E = Field measured Eh with Ag/AgCL KCL electrode, mV

    T = Groundwater Temperature, $^{\circ}$C
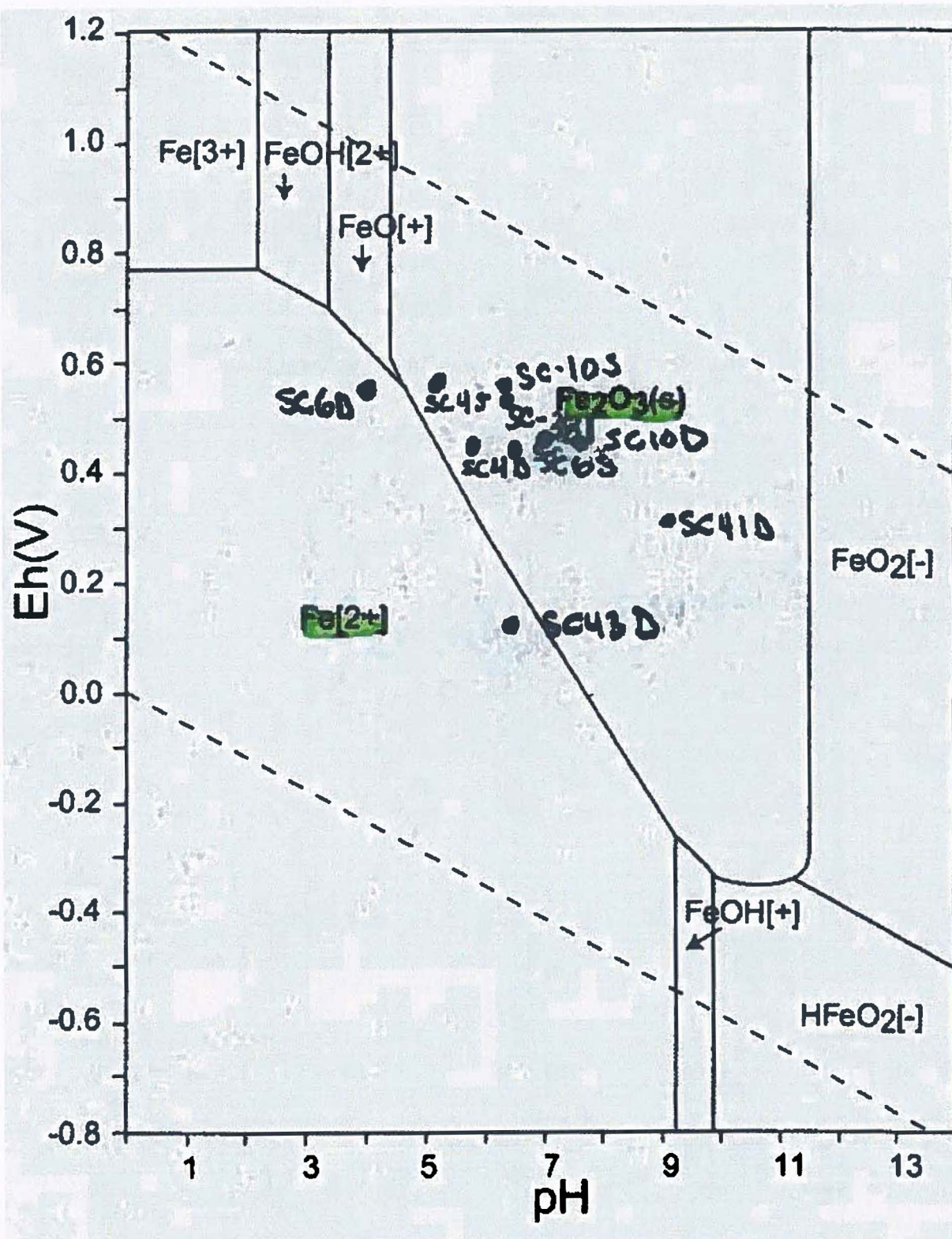
Eh-pH Diagram for Iron Showing Predominant Forms of Iron at Well Locations Downgradient of Facility

Eh-pH Diagram for Chromium showing October 2012 data for wells located between

Facility and Farm Parcel

● MONITORING WELL LOCATED BETWEEN FACILITY AND FARM PARCEL

● WELL LOCATED IMMEDIATELY UPGRADIENT OF CAR WASH — PRE-CPS INJECTION
OCTOBER 2009 — April 2011

L = LAYNE WELL (UPPER AQUIFER)

W-9 = WELL W-9 (LOWER AQUIFER)

A = A WELL   (LOWER AQUIFER)

B = B-WELL (UPPER AQUIFER)

Attachment 2
Summary of Redox and pH Data
For Upper and Lower Aquifer
Upgradient of Car Wash
Shieldalloy Site
Newfield, NJ

Well W9 Date	pH	Field ORP	Adjusted ORP		Layne Well Date	pH	Field ORP	Adjusted ORP
October-09	6.25	158	371.7		October-09	8.53	15	228.7
January-10	9.27	-23	190.7		December-09	5.95	90	303.7
April-10	6.89	NA	NA		January-10	7.45	84	297.7
October-10	8.53	NA	NA		April-10	6.36	NA	NA
April-11	8.7	154	367.7		October-10	7.52	NA	NA
					April-11	7.49	262	475.7

Well A Date	pH	Field ORP	Adjusted ORP		Well B Date	pH	Field ORP	Adjusted ORP
April-09	6.46	NM	NM		April-09	7.65	NM	NC
October-09	8.47	NA	NA		October-09	NA	NA	NA
January-10	8.61	-184	29.7		January-10	8.14	-212	1.7
April-10	6.83	NA	NA		April-10	7.02	NA	NA
October-10	8.26	NA	NA		October-10	7.24	NA	NA
April-11	7.86	137	350.7		April-11	8.23	9	222.7

Notes:

Adjusted ORP reflects adjustments made to field measured ORP using Ag/AgCl KCL electrode to Hydrogen Electrode using the following formula:

$$Adjusted\ ORP = (ORP_{field} + 206\ mV) - 0.7(groundwater\ temperature - 25\,^{\circ}C).$$

Adjusted ORP based upon groundwater temperature approximately 14°C.

NM = not measured.

NA = not available.

NC = not calculated.

**ATTACHMENT 3
CHROMIUM REDUCTION DATA FOR CONTROL SAMPLES
FROM TREATABILITY STUDIES**

Attachment 3 Summary of Chromium Reductions Observed in Treatability Testing Controls (Untreated Soils)				
Study	**Plume Zone**	**Test Period (days)**	**Hexavalent Chromium Removed from Solution (mg)**	**Total Chromium Removed from Solution (mg)**
Control samples (untreated/buffered) – Substrate Batch Tests	Deep Zone – Well SC-2D(R)	70	2.91 to 3.63 (>90%)	3.20 (91%)
Control samples (untreated/unbuffered) – Substrate batch tests	Deep Zone – Well SC-2D(R)	29	1.4 (65%)	Not Measured
Control samples – CPS Batch Tests	Deep Zone – Well SC2-D(R)	21	1.8 to 2.0 (60 to 70%)	Not Measured
Control Column – mZVI Column Study	Shallow Zone – GW from well IW-2	68	13.4 (9%)	23.8 (15%)
Control Column – mZVI Column Study	Deep Zone – Well SC-2D(R)	53	254 (41%)	178 (26%)
Batch tests on soils from untreated control columns after mZVI Column Study	Shallow Zone- Well IW-2	21	14 to 20 (25 to 36%)	Not Measured
Batch tests on soils from untreated control columns after mZVI Column Study	Deep Zone – Well SC-2D(R)	21	11 to 22 (20 to 40%)	Not Measured

See following pages for data used to compile this table

Attachment 3
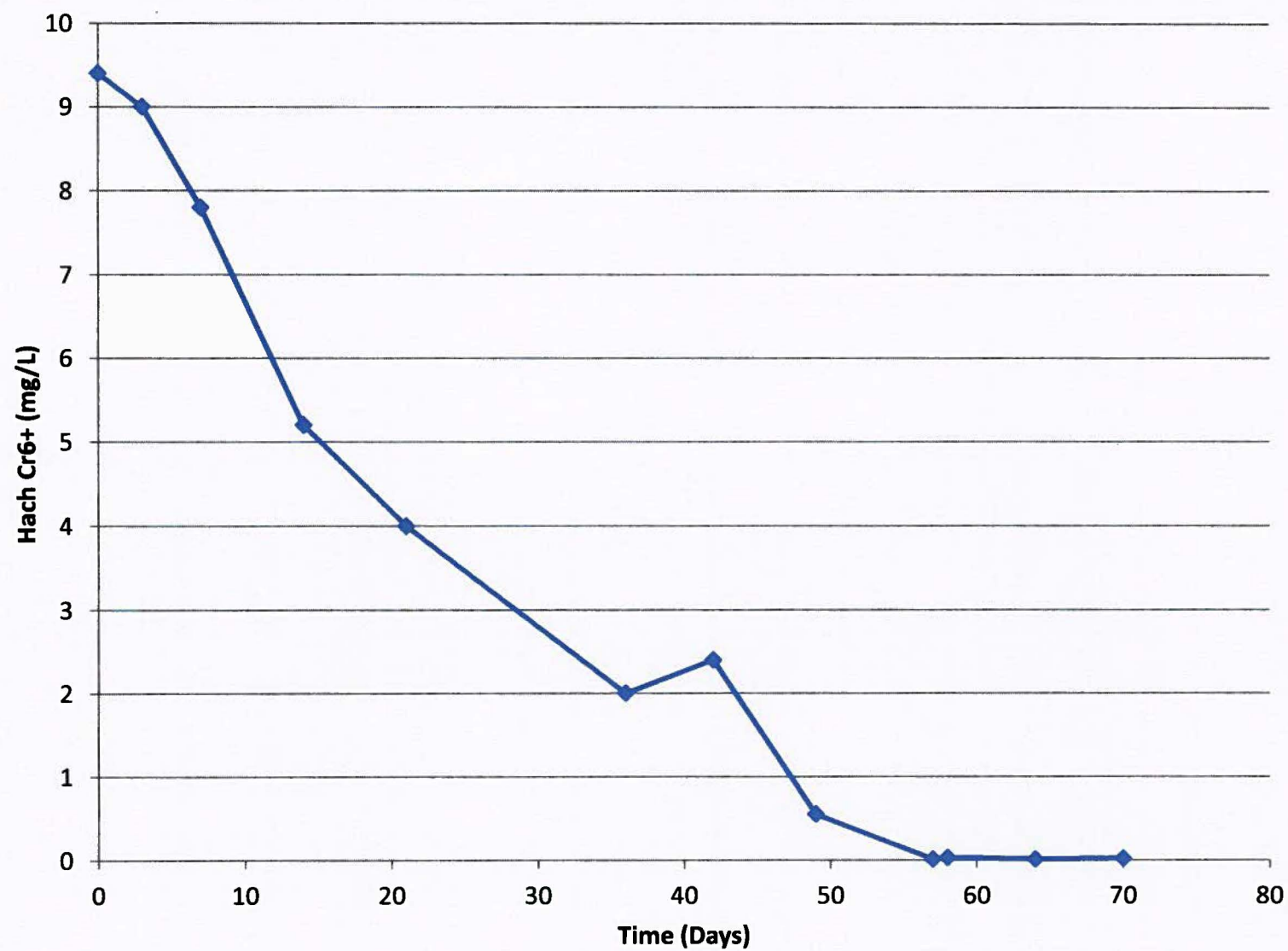**Shield Alloy Batch Treatability Test Data**
Results of Batch Testing of Soil from Deep Zone at Farm Parcel
**Control (untreated) Soil (Buffered and Unbuffered Samples)**

Control 1A 400 g Deep Soil + 330 mL Groundwater from SC2D(R) - Control A - Buffered with 0.25 g Sodium Bicarbonate													
Time	Day	0	3	7	14	21	36	42	49	57	58	64	70
pH	SU	7.9	6.6	6.5	6.5	6.8	6.9	6.6	6.7	6.2	6.6	2.3	3.1
ORP	mV	-117	48	38	183	110	89	105	53	60	156	343	161
Hach Hex Chromium	mg/L	9.4	9.0	7.8	5.2	4.0	2.0	2.4	0.6	0.01	0.03	0.01	0.02
Mass Cr^{6+} in Solution	mg	3.10	2.97	2.57	1.72	1.32	0.66	0.79	0.18	0.00	0.01	0.00	0.01
Amount of Hexavalent Chromium Removed From Solution =				**3.10 mg**		**99.8% Reduction**							

Control 1B 400 g Deep Soil + 330 mL Groundwater from SC2D(R) Buffered with 0.25 g Sodium Bicarbonate				
Time	Day	0	36	70
pH	SU	8.0	6.5	5.9
ORP	mV	-109	112	33
Hach Kit Hex Chromium	mg/L	9.2	3.6	0.38
Mass Cr^{6+} in Solution	mg	3.04	1.19	0.13
Amount of Hexavalent Chromium Removed From Solution =			**2.91 mg**	**95.9% Reduction**

AW Lab Hex Chromium	mg/L	12	4.3	1.0
Mass Cr^{6+} in Solution	mg	3.96	1.42	0.33
Amount of Hexavalent Chromium Removed From Solution =			**3.63 mg**	**91.7% Reduction**

AW Lab Total Chromium	mg/L	10.7	4.1	1.0
Mass Cr_{total} in Solution	mg	3.53	1.35	0.33
Amount of Total Chromium Removed From Solution =			**3.20 mg**	**90.7% Reduction**

513 g Deep Soil + 270 mL Groundwater from SCD2(R) - Unbuffered Sample				
Time	Day	0	11	29
pH	SU	5.8	6	4.3
ORP	mV	-30	90	220
Hach Kit Hex Chromium	mg/L	8	4.2	2.8
Mass Cr6+ in Solution	mg	2.16	1.134	0.756
Amount of Hexavalent Chromium Removed from Solution =			**1.40 mg**	**65.0% Reduction**

Greater reduction expected if duration of test run longer. Similar reductions were observed in buffered and unbuffered samples at similar times during tests.

Subtrate Batch Test: Attenuation of Cr6+ in Buffered Control Sample
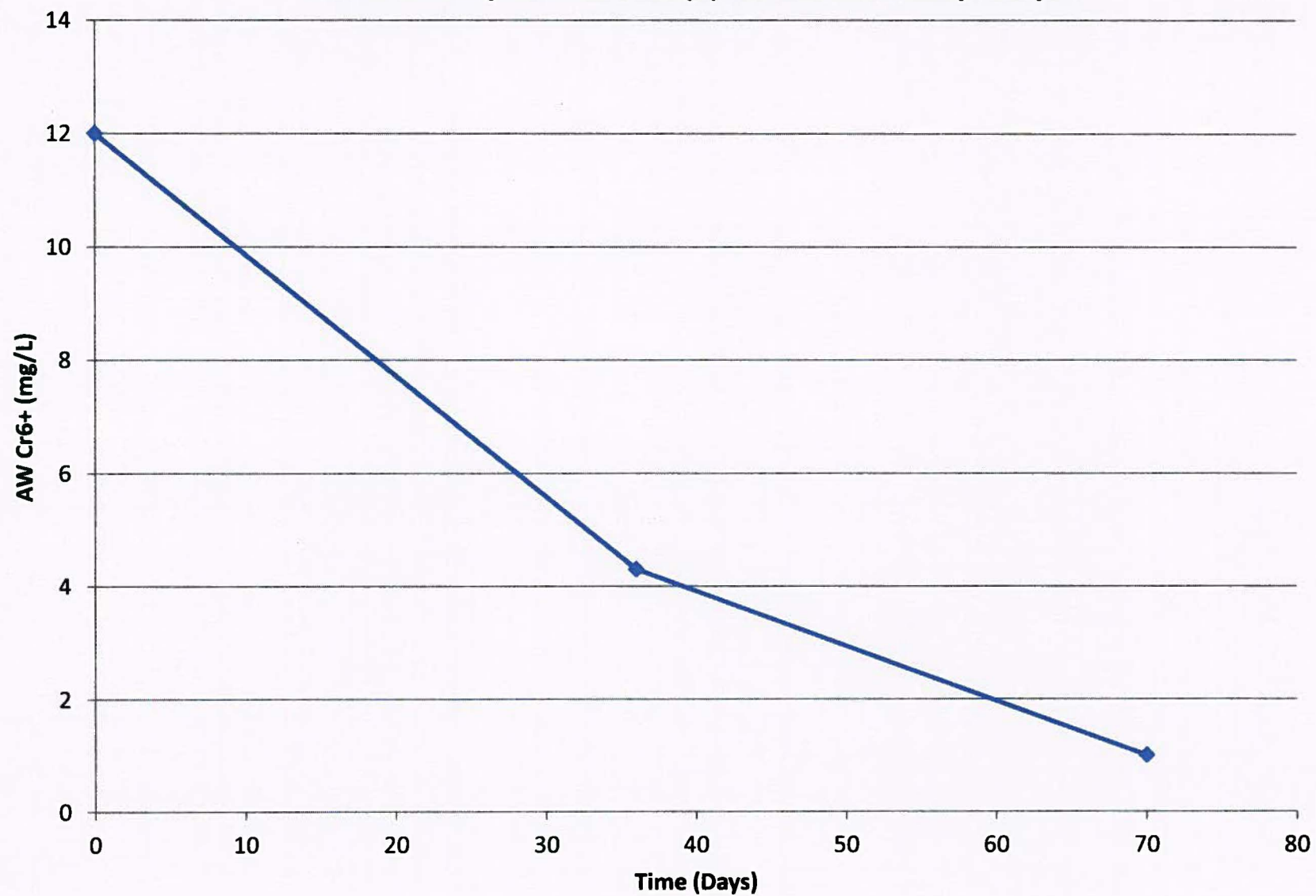Bottle A - Deep Soil + SCD2(R) GW

Subtrate Batch Tests: Attenuation of Cr6+ in Buffered Control Sample
Bottle B - Deep Soil and SC2D(R) GW Hach Test Kit Analysis
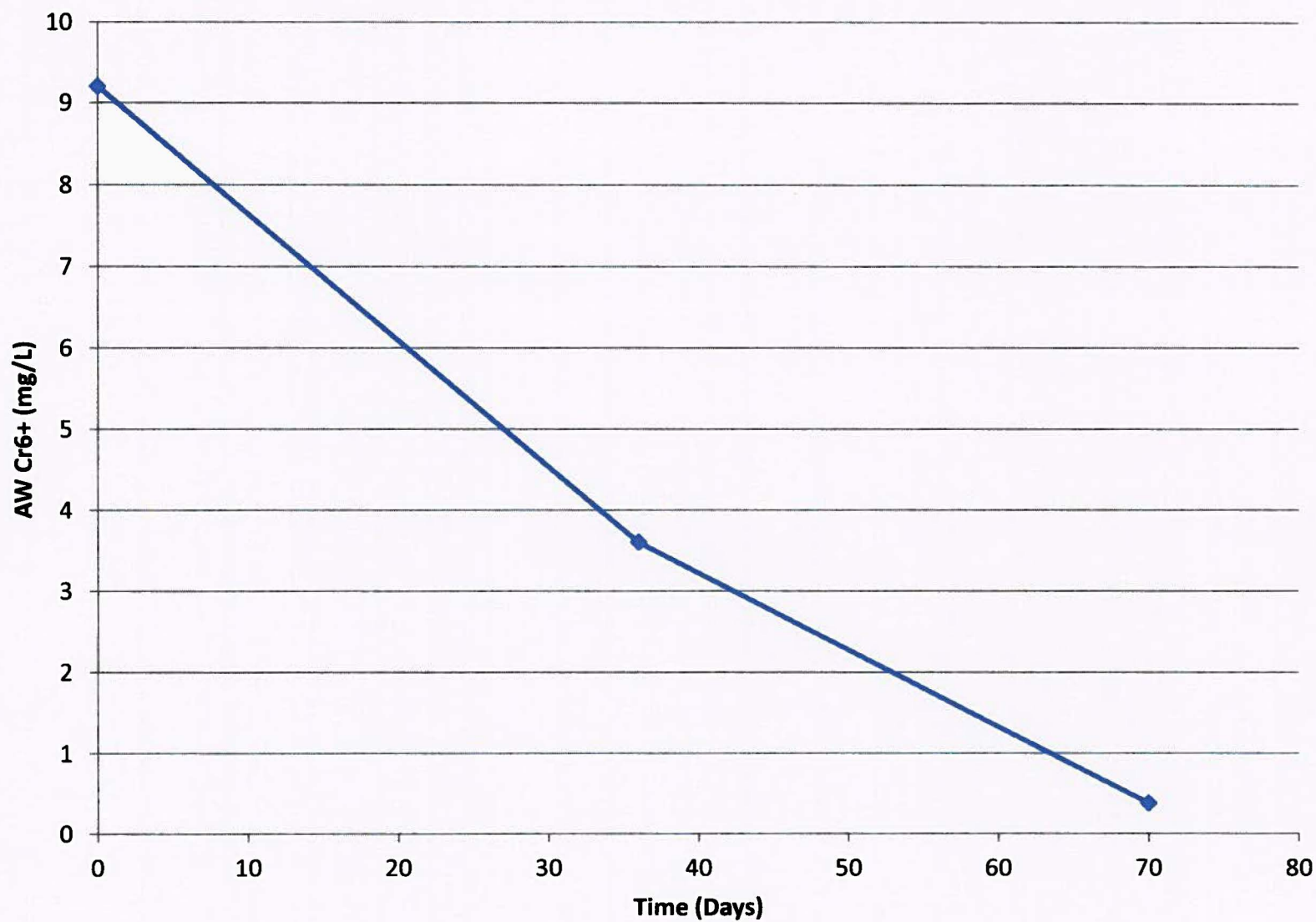
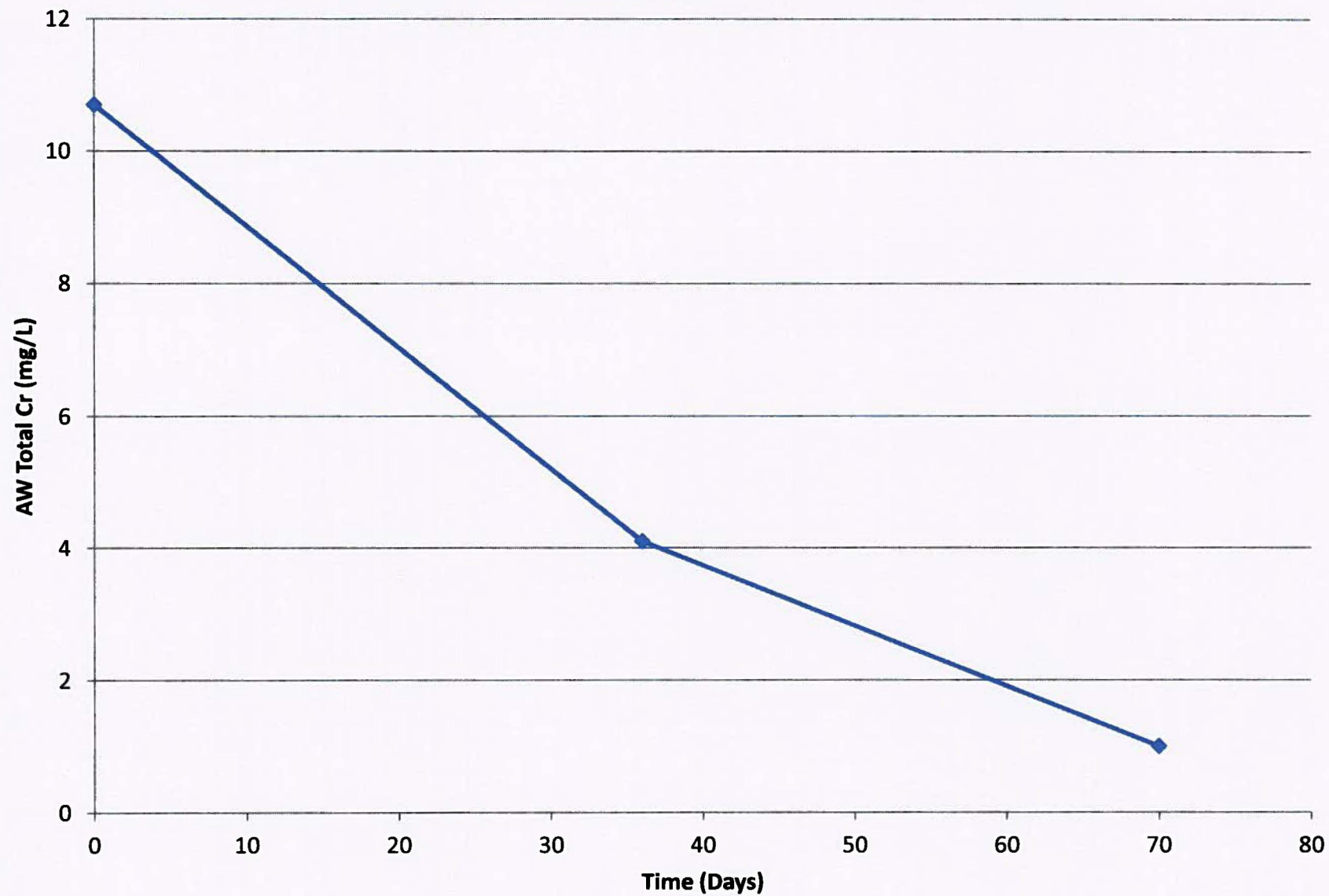Subtrate Batch Tests: Attenuation of Cr6+ in Buffered Control Sample
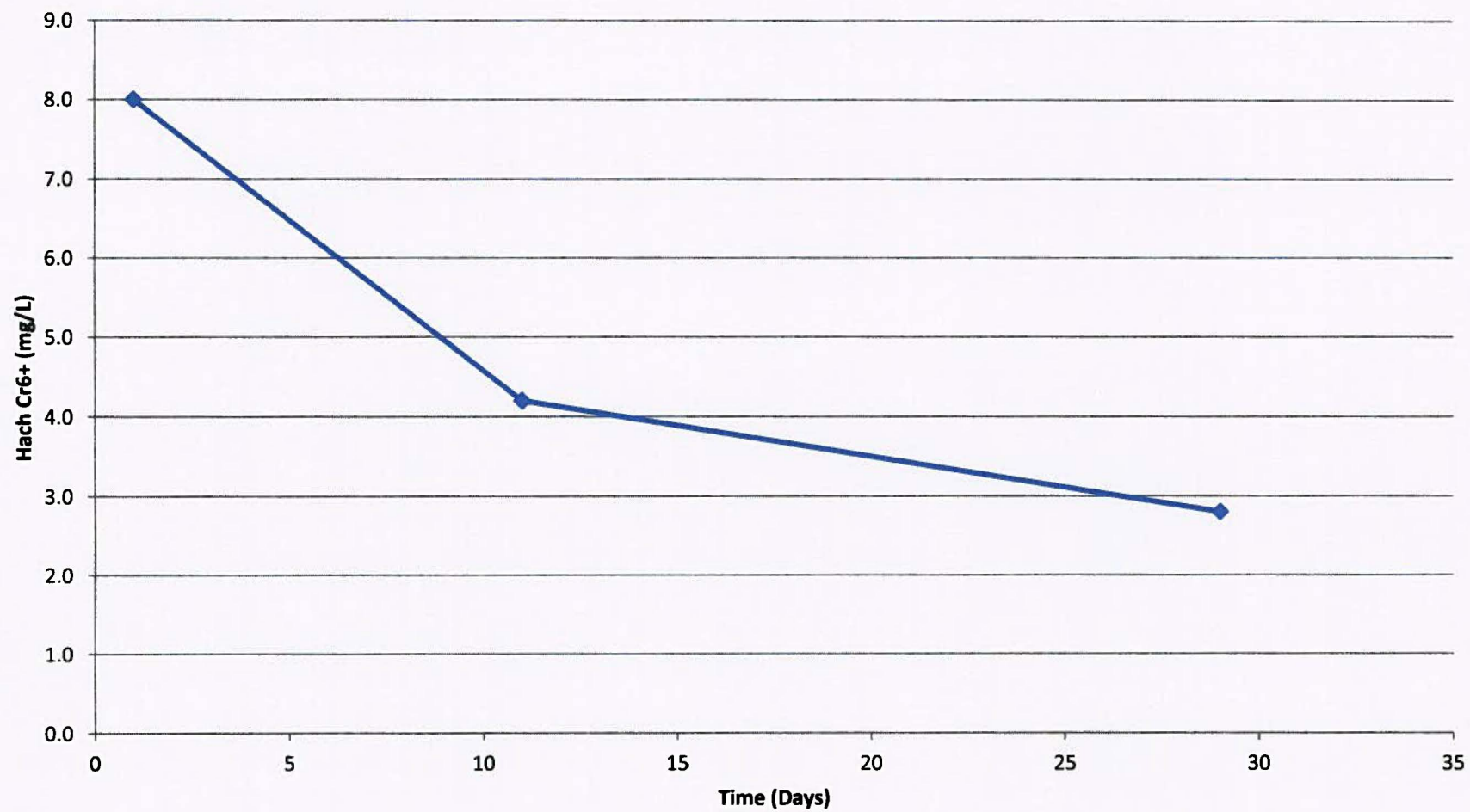Bottle B - Deep Soil and SC2D(R) GW AW Laboratory Analysis

Subtrate Batch Tests: Attenuation of Total Chromium Buffered Sample
Bottle B - Deep Soil and SC2D(R) GW AW Laboratory Analysis

Batch Test: Attenuation of Cr6+ in Unbuffered Control Sample
Deep Soil + SC-2D(R) GW

Attachment 3
Shield Alloy Batch Treatability Test Data
Results of Testing of Soil from Deep Zone at the Farm Parcel
Control Samples (No Amendments) from Calcium Polysulfide Batch Treatability Study

<u>Cascade CaSx Test</u>

1H Deep Plume Zone Soil Control 400 g Soil + 331 mL GW from SC2D(R)

Time	Day		0	1	2	5	6	7	8	9	12	13	14	15	16	19	20	21
pH	SR		6.2	6.7	6.5	6.9	6.9	6.8	7.4	6.9	7.2	7.4	7.1	8.0	6.9	6.9	7.1	6.9
ORP	mV		-36	66	236	134	91	125	110	267	216	226	293	273	164	175	200	455
Hex Cr (Hach Kit)	mg/L		9.0	8.6	7.4	7.0	1.6	4.2	4.8	4.6	4.8	6.4	4.2	4.0	1.6	3.4	3.2	3.6
Mass Hex Chrome in Solution	mg		3.0	2.8	2.4	2.3	0.5	1.4	1.6	1.5	1.6	2.1	1.4	1.3	0.5	1.1	1.1	1.2
Amount of Hex Chrome Removed from Solution		1.8 mg		60.0% Removed														

9Sx Deep Plume Zone Control 400 g Soil + 294 mL GW from SC2D(R)

Time	Day		0	1	2	3	7	8	9	10	13	14	15	17	20	21
pH	SR		5.9	6.0	4.6	5.1	6.4	4.6	6.1	6.1	6.2	5.7	5.9	2.9	5.2	4.0
ORP	mV		240	253	343	344	213	244	194	70	250	197	112	290	257	244
Hex Cr	mg/L		9.4	7.6	6.0	5.2	6.2	5.6	4.6	4.6	5.4	4.8	5.8	4.6	2.6	2.8
Mass Hex Chrome in Solution	mg		2.8	2.3	1.8	1.5	1.8	1.7	1.4	1.4	1.6	1.4	1.7	1.4	0.8	0.8
Amount of Hex Chrome Removed from Solution		2.0 mg		70.2% Removed												

CPS Batch Tests: Attenuation of Cr6+ in Control Samples 1H and 9Sx
Deep Soil + SC-2D(R) GW
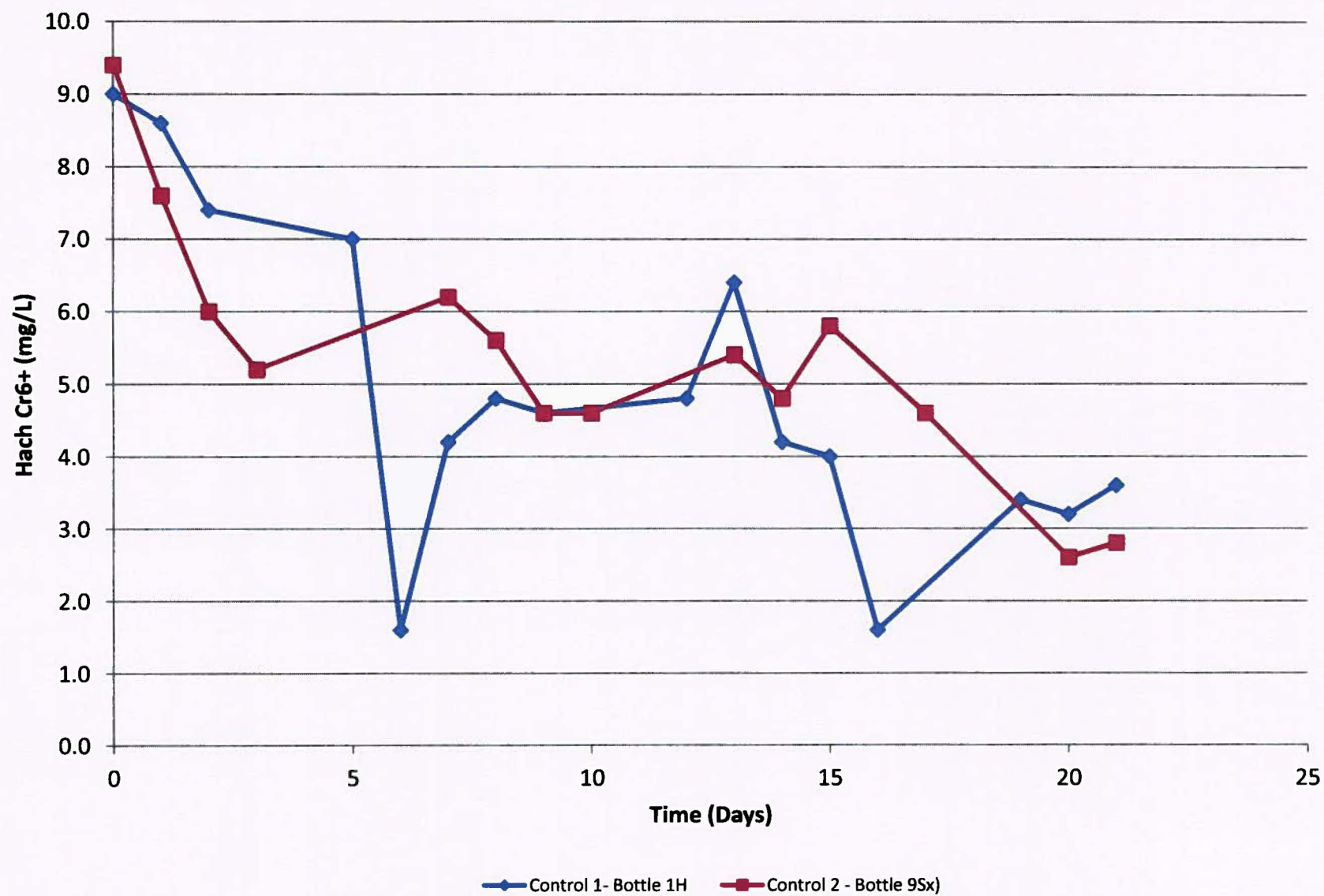
Attachment 3
Shield Alloy mZVI Column Test Data
Control (untreated) Columns Soils
from Shallow and Deep Plumes at Farm Parcel
for mZVI Evaluation

Mass Balance - Column 1 - ZVI Control-Shallow Plume Zone - Soil/Groundwater from IW-2

Total Soil Mass =		1,855	g	
Initial Soil Concentration CR(VI) =	1.8		mg/kg	
Initial Soil Concentration CR(total) =	0.01		mg/kg	
Final Soil Concentration CR(VI) =	2.4		mg/kg	
Final Soil Concentration CR(total) =	13		mg/kg	
Removed CR(VI) mass in column =	**13.4**		mg	
Δ - Final Sorbed CR(VI) mass on soil =		1.07	mg	
Δ - precipitated CR(total) mass on soil =		**23.8**	mg	
Total Cr(Total) mass throughput in effluent =	130		mg	
Total Cr(Total) mass throughput in influent =	156		mg	
Percent Removal of Cr(total) =	**15%**			
Total Cr(VI) mass in influent throughout duration =		158	mg	Lab Method
Percent Removal of Cr(VI) =	**9%**			
Effective Treatment Zone Thickness =	18		inches	

Mass Balance - ZVI Control Column 4 - Deep Plume Zone - Soil/Groundwater from SC-2DR

Total Soil Mass =		1,860	g	
Initial Soil Concentration CR(VI) =	0.01		mg/kg	
Initial Soil Concentration CR(total) =	10.8		mg/kg	
Final Soil Concentration CR(VI) =	0.01		mg/kg	
Final Soil Concentration CR(total) =	107		mg/kg	
Removed CR(VI) mass in column =	**254**		mg	
Δ - Final Sorbed CR(VI) mass on soil =	0.00		mg	
Δ - precipitated CR(total) mass on soil =	**178**		mg	
Total Cr(Total) mass in effluent =	456		mg	
Total Cr(Total) mass in influent =	680		mg	
Percent Removal of Cr(total) =	**26%**			
Total Cr(VI) mass in influent throughout duration =		613	mg	Hach Method
Percent Removal of Cr(VI) =	**41%**			
Effective Treatment Zone Thickness =	18		inches	

Attachment 3
Shield Alloy mZVI Column Test Data
Control (untreated) Columns Soils
from Shallow and Deep Plumes at Farm Parcel
for mZVI Evaluation

IW-2 GW Influent

Date & Time Start	pH	ORP	Hach Hex Cr	Hach Hex Cr	AW Hex Cr	AW Total Cr
	SU	mV	mg/L	C/Co	mg/L	mg/L
1/4/10 14:15	7.0	130	2.2	1.0		
1/6/10 10:00	7.2	12	0.1	1.0	2.23	2.13
1/7/10 10:00	6.9	102	1.4	1.0		
1/8/10 14:00	7.7	90	1.68	1.0		
1/13/10 10:15	7.8	51	2.2	1.0	2.28	2.87
1/15/10 13:30	6.7	56	2.1	1.0		
1/18/10 12:35	7.1	57	2.0	1.0		
1/20/10 10:30					2.67	1.99
1/27/10 9:00	7.0	103	2.2	1.0	2.29	2.08
2/4/10 16:30	6.5	-37	2.45	1.0	2.9	2.23
2/11/10 13:25	7.0	106	1.96	1.0	2.35	2.18
2/17/10 8:32	6.7	77	1.8	1.0	3.16	2.32
2/24/10 10:15	7.2	130	2.4	1.0	3.16	2.59
3/3/2010 8:30	6.7	60	4.0	1.0		
3/11/2010 9:30	7.4	210	4.4	1.0	4.3	4.4
	7.1		2.21		2.82	2.53

Shield Alloy mZVI Column Test Data
Control (untreated) Columns Soils
from Shallow and Deep Plumes at Farm Parcel
for mZVI Evaluation

1 Shallow Soil (1855 g) + IW-2 GW Control 340 mL Pore Volume

Date & Time Start	Date & Time Sample	Minutes Run	Volume Collected mL	Cumulative Volume mL	Pore Volumes
12/21/09 19:30	12/22/09 16:00	1230	167	167	0.49
12/23/09 13:00	12/23/09 16:00	180	31	198	0.58
1/2/10 13:20	1/4/10 14:15	2935	432	630	1.85
1/4/10 16:30	1/5/10 14:30	1320	217	847	2.49
1/5/10 16:30	1/6/10 10:00	1050	141	988	2.91
1/6/10 10:50	1/7/10 16:30	1780	246	1234	3.63
1/7/10 16:48	1/8/10 14:00	1272	174	1408	4.14
1/8/10 14:30	1/11/10 14:00	4290	575	1983	5.83
1/11/10 15:30	1/12/10 14:15	1365	188	2171	6.39
1/12/10 16:00	1/13/10 10:15	1095	149	2320	6.82
1/13/10 11:00	1/14/10 14:42	1662	653	2973	8.74
1/14/10 15:00	1/15/10 13:30	1350	543	3516	10.34
1/15/10 14:00	1/18/10 12:35	4235	1684	5200	15.29
1/18/10 14:00	1/19/10 14:54	1494	586	5786	17.02
1/19/10 16:10	1/20/10 10:30	1100	414	6200	18.24
1/20/10 11:10	1/21/10 13:15	1565	593	6793	19.98
1/21/10 16:00	1/22/10 13:04	1264	466	7259	21.35
1/22/10 16:00	1/25/10 14:45	4245	1623	8882	26.12
1/25/10 15:15	1/26/10 14:30	1395	508	9390	27.62
1/26/10 16:30	1/27/10 9:00	990	376	9766	28.72
1/27/10 9:17	1/28/10 15:10	1793	1360	11126	32.72
1/28/10 16:45	1/29/10 14:20	1295	1111	12237	35.99
1/29/10 15:33	2/1/10 13:30	4197	3660	15897	46.76
2/1/10 14:30	2/2/10 10:05	1175	1076	16973	49.92
2/2/10 12:10	2/3/10 14:45	1595	1044	18017	52.99
2/3/10 16:20	2/4/10 16:30	1450	151	18168	53.44
2/4/10 17:45	2/5/10 10:45	1020	1014	19182	56.42
2/5/10 14:30	2/8/10 13:30	4260	3975	23157	68.11
2/8/10 15:00	2/9/10 13:18	1338	1250	24407	71.79
2/9/10 15:00	2/11/10 13:25	2785	2629	27036	79.52
2/11/10 15:24	2/12/10 14:50	1406	2846	29882	87.89
2/12/10 16:50	2/13/10 9:20	990	1950	31832	93.62
2/13/10 9:52	2/14/10 12:05	1573	3135	34967	102.84
2/14/10 12:22	2/15/10 8:50	1228	2448	37415	110.04
2/15/10 11:35	2/16/10 11:10	1415	2796	40211	118.27
2/16/10 14:37	2/17/10 8:32	1075	2121	42332	124.51
2/17/10 9:00	2/18/10 8:25	1405	2874	45206	132.96
2/18/10 13:53	2/19/10 8:50	1137	2233	47439	139.53
2/19/10 11:00	2/20/10 10:15	1395	2749	50188	147.61
2/20/10 10:35	2/21/10 11:25	1490	2919	53107	156.20
2/21/10 12:15	2/22/10 9:34	1279	2571	55678	163.76
2/22/10 13:30	2/23/10 16:30	1620	3265	58943	173.36
2/23/10 17:55	2/24/10 10:15	980	1935	60878	179.05
2/24/10 10:57	2/25/10 8:20	1283	1332	62210	182.97

Total Volume throughput   61580

Shield Alloy mZVI Column Test Data
Control (untreated) Columns Soils
from Shallow and Deep Plumes at Farm Parcel
for mZVI Evaluation

1 Shallow Soil (1855 g) + IW-2 GW Control 340 mL Pore Volume

Date & Time Start	Date & Time Sample	Flow Rate mL/min	pH SU	ORP mV	Hach Hex Cr mg/L	Hach Hex Cr C/Co	Hach Hex Cr mg Removed	AW Hex Cr mg/L	AW Total Cr mg/L
12/21/09 19:30	12/22/09 16:00	0.136							
12/23/09 13:00	12/23/09 16:00	0.172							
1/2/10 13:20	1/4/10 14:15	0.147	7.2	251	0.00	0.00	1.0		
1/4/10 16:30	1/5/10 14:30	0.164	7.1	156	0.10	0.05	1.4		
1/5/10 16:30	1/6/10 10:00	0.134	7.3	104	0.10	0.06	1.6		
1/6/10 10:50	1/7/10 16:30	0.138	6.8	42	0.02	0.01	2.0	<0.02	<0.05
1/7/10 16:48	1/8/10 14:00	0.137	7.5	92	0.01	0.01	2.2		
1/8/10 14:30	1/11/10 14:00	0.134	7.2	140	0.14	0.08	3.1		
1/11/10 15:30	1/12/10 14:15	0.138	6.6	150	0.05	0.03	3.4		
1/12/10 16:00	1/13/10 10:15	0.136	7.8	80	0.08	0.04	3.8		
1/13/10 11:00	1/14/10 14:42	0.393	7.3	66	0.02	0.01	5.2	0.13	0.13
1/14/10 15:00	1/15/10 13:30	0.402	8.4	15	0.70	0.33	5.9		
1/15/10 14:00	1/18/10 12:35	0.398	7.1	47	0.29	0.14	9.0		
1/18/10 14:00	1/19/10 14:54	0.392	6.9	73	1.35	0.68	9.4		
1/19/10 16:10	1/20/10 10:30	0.376	7.9	54	1.65	0.83	9.5	1.26	1.48
1/20/10 11:10	1/21/10 13:15	0.379	7.3	142	2.0	1.00	9.5		
1/21/10 16:00	1/22/10 13:04	0.369	7.6	126	3.0	1.50	9.0		
1/22/10 16:00	1/25/10 14:45	0.382	7.2	139	2.4	1.20	8.4		
1/25/10 15:15	1/26/10 14:30	0.364	9.1	105	2.8	1.40	8.0		
1/26/10 16:30	1/27/10 9:00	0.380	7.0	-37	2.2	1.00	8.0	1.96	1.93
1/27/10 9:17	1/28/10 15:10	0.759	8.5	20	2.4	1.09	7.7		
1/28/10 16:45	1/29/10 14:20	0.858	8.6	-17	3.4	1.55	6.4		
1/29/10 15:33	2/1/10 13:30	0.872	8.2	62	2.8	1.27	4.2		
2/1/10 14:30	2/2/10 10:05	0.916	8.8	6	3.0	1.36	3.3		
2/2/10 12:10	2/3/10 14:45	0.655	10.0	-116	2.8	1.27	2.7		
2/3/10 16:20	2/4/10 16:30	0.104	7.8	-105	2.8	1.14	2.6	2.5	2.21
2/4/10 17:45	2/5/10 10:45	0.994		90	2.2	0.90	2.9		
2/5/10 14:30	2/8/10 13:30	0.933	8.3	-43	0.4	0.16	11.0		
2/8/10 15:00	2/9/10 13:18	0.934	7.5	-16	1.0	0.41	12.9		
2/9/10 15:00	2/11/10 13:25	0.944	8.7	25	1.95	0.99	12.9		
2/11/10 15:24	2/12/10 14:50	2.024	8.2	-37	1.4	0.71	14.5	2.28	2.26
2/12/10 16:50	2/13/10 9:20	1.970							
2/13/10 9:52	2/14/10 12:05	1.993			1.1	0.56	17.2		
2/14/10 12:22	2/15/10 8:50	1.993	8.1	17	1.1	0.56	19.3		
2/15/10 11:35	2/16/10 11:10	1.976	8.4	20	2.6	1.33	17.5		
2/16/10 14:37	2/17/10 8:32	1.973	8.3	23	1.8	0.92	17.8	2.78	2.08
2/17/10 9:00	2/18/10 8:25	2.046	9.0	10	1.6	0.89	18.4		
2/18/10 13:53	2/19/10 8:50	1.964	8.0	1	2.0	1.11	18.0		
2/19/10 11:00	2/20/10 10:15	1.971					22.9		
2/20/10 10:35	2/21/10 11:25	1.959			2.35	1.31	21.3		
2/21/10 12:15	2/22/10 9:34	2.010	7.5	17	1.2	0.67	22.8		
2/22/10 13:30	2/23/10 16:30	2.015	7.4	37	3.7	2.06	16.6		
2/23/10 17:55	2/24/10 10:15	1.974	6.7	82	3.4	1.89	13.5	2.78	2.74
2/24/10 10:57	2/25/10 8:20	1.038	8.0	53	2.5	1.04	13.4		
		Average	7.8						
								Average	2.1

Attachment 3
Shield Alloy mZVI Column Test Data
Control (untreated) Columns Soils
from Shallow and Deep Plumes at Farm Parcel
for mZVI Evaluation

SC2D(R) GW Influent

Date & Time Start	pH	ORP	Spec. Cond.	DO	Headspace H2S	Hach Hex Cr	Hach Hex Cr	AW Hex Cr	AW Total Cr
	SU	mV	uS/cm	mg/L	ppm	mg/L	C/Co	mg/L	mg/L
1/4/10 14:15	6.8	161	140	4.8		10.0	1.00		
1/6/10 10:00	7.0	109		4.2		11.4	1.00	12.4	11.6
1/7/10 10:00	6.7	86	145	4.0		11.0	1.00		
1/8/10 14:00	7.0	20	142	4.6		11.0	1.00		
1/13/10 10:15	7.1	90	158	4.7		10.4	1.00	8.47	12.1
1/15/10 13:30	6.4	129	153	4.2	0	11.2	1.00		
1/18/10 12:35	6.7	97	159	3.4		9.4	1.00		
1/20/10 10:30								11.9	11.6
1/27/10 9:00	6.2	142				11.6	1.00	12.8	11.5
2/4/10 16:30	8.5	-15				13.6	1.00	23.0	11.2
2/11/10 13:25	6.7	135		3.1		11.2	1.00	12.6	15.1
2/11/10 13:25								11.8	11.9
2/17/10 8:32	9.4	63		4.0		11.0	1.00	12.0	13.1
2/24/10 10:15	6.9	134		4.7		10.0	1.00	12.0	12.5
3/3/10 10:00	5.9	144		4.1		10.4	1.00		
3/11/10 9:30	7.0	267		5.0		10.8	1.00	10.5	11.1
	7					10.9		12.7	12.2

Shield Alloy mZVI Column Test Data
Control (untreated) Columns Soils
from Shallow and Deep Plumes at Farm Parcel
for mZVI Evaluation

4 Deep Soil (1860 g) + SC2D(R) GW Control 340 mL Pore Volume

Date & Time Start	Date & Time Sample	Minutes Run	Volume Collected mL	Cumulative Volume mL	Pore Volumes	Flow Rate mL/min
12/21/09 19:30	12/22/09 16:00	1230	157	157	0.46	0.128
12/23/09 13:00	12/23/09 16:00	180	26	183	0.54	0.144
1/2/10 13:20	1/4/10 14:15	2935	370	553	1.63	0.126
1/4/10 16:30	1/5/10 14:30	1320	170	723	2.13	0.129
1/5/10 16:30	1/6/10 10:00	1050	143	866	2.55	0.128
1/6/10 10:50	1/7/10 16:30	1780	224	1090	3.21	0.126
1/7/10 16:48	1/8/10 14:00	1272	160	1250	3.68	0.126
1/8/10 14:30	1/11/10 14:00	4290	525	1775	5.22	0.122
1/11/10 15:30	1/12/10 14:15	1365	172	1947	5.73	0.126
1/12/10 16:00	1/13/10 10:15	1095	136	2083	6.13	0.124
1/13/10 11:00	1/14/10 14:42	1662	578	2661	7.83	0.348
1/14/10 15:00	1/15/10 13:30	1350	493	3154	9.28	0.365
1/15/10 14:00	1/18/10 12:35	4235	1555	4709	13.85	0.367
1/18/10 14:00	1/19/10 14:54	1494	603	5312	15.62	0.404
1/19/10 16:10	1/20/10 10:30	1100	378	5690	16.74	0.344
1/20/10 11:10	1/21/10 13:15	1565	551	6241	18.36	0.352
1/21/10 16:00	1/22/10 13:04	1264	449	6690	19.68	0.355
1/22/10 16:00	1/25/10 14:45	4245	1498	8188	24.08	0.353
1/25/10 15:15	1/26/10 14:30	1395	499	8687	25.55	0.358
1/26/10 16:30	1/27/10 9:00	990	352	9039	26.59	0.356
1/27/10 9:17	1/28/10 15:10	1793	1228	10267	30.20	0.685
1/28/10 16:45	1/29/10 14:20	1295	1088	11355	33.40	0.840
1/29/10 15:33	2/1/10 13:30	4197	3226	14581	42.89	0.769
2/1/10 14:30	2/2/10 10:05	1175	1017	15598	45.88	0.866
2/2/10 12:10	2/3/10 14:45	1595	1384	16982	49.95	0.868
2/3/10 16:20	2/4/10 16:30	1450	1211	18193	53.51	0.835
2/4/10 17:45	2/5/10 10:45	1020	914	19107	56.20	0.896
2/5/10 14:30	2/8/10 13:30	4260	3611	22718	66.82	0.848
2/8/10 15:00	2/9/10 13:18	1338	1137	23855	70.16	0.850
2/9/10 15:00	2/11/10 13:25	2785	2395	26250	77.21	0.860
2/11/10 15:24	2/12/10 14:50	1406	2381	28631	84.21	1.693
2/12/10 16:50	2/13/10 9:20	990	1783	30414	89.45	1.801
2/13/10 9:52	2/14/10 12:05	1573	2857	33271	97.86	1.816
2/14/10 12:22	2/15/10 8:50	1228	2217	35488	104.38	1.805
2/15/10 11:35	2/16/10 11:10	1415	2446	37934	111.57	1.729
2/16/10 14:37	2/17/10 8:32	1075	1896	39830	117.15	1.764
2/17/10 9:00	2/18/10 8:25	1405	1787	41617	122.40	1.272
2/18/10 13:53	2/19/10 8:50	1137	8	41625	122.43	0.007
2/19/10 11:00	2/20/10 10:15	1395	2463	44088	129.67	1.766
2/20/10 10:35	2/21/10 11:25	1490	2663	46751	137.50	1.787
2/21/10 12:15	2/22/10 9:34	1279	2333	49084	144.36	1.824
2/22/10 13:30	2/23/10 16:30	1620	2941	52025	153.01	1.815
2/23/10 17:55	2/24/10 10:15	980	1747	53772	158.15	1.783
2/24/10 10:57	2/25/10 8:20	1283	2285	56057	164.87	1.781

55874

Attachment 3
Shield Alloy mZVI Column Test Data
Control (untreated) Columns Soils
from Shallow and Deep Plumes at Farm Parcel
for mZVI Evaluation

4 Deep Soil (1860 g) + SC2D(R) GW Control 340 mL Pore Volume

| Date & Time Start	Date & Time Sample	pH SU	ORP mV	Hach Hex Cr mg/L	Hach Hex Cr C/Co	Hach Hex Cr mg Removed	AW Hex Cr mg/L	AW Total Cr mg/L
12/21/09 19:30	12/22/09 16:00							
12/23/09 13:00	12/23/09 16:00							
1/2/10 13:20	1/4/10 14:15	3.6	270	0	0.00	3.7		
1/4/10 16:30	1/5/10 14:30	4.8	252	0.2	0.02	5.4		
1/5/10 16:30	1/6/10 10:00	4.6	211	0.02	0.00	6.8		
1/6/10 10:50	1/7/10 16:30	5.5	29	0.01	0.00	9.3	<0.02	<0.05
1/7/10 16:48	1/8/10 14:00	7.0	60	0.01	0.00	11.0		
1/8/10 14:30	1/11/10 14:00	5.2	63	0.00	0.00	16.8		
1/11/10 15:30	1/12/10 14:15	5.9	284	0.00	0.00	18.7		
1/12/10 16:00	1/13/10 10:15	6.6	112	0.01	0.00	20.1	<0.04	<0.05
1/13/10 11:00	1/14/10 14:42	7.7	89	0.02	0.00	26.1		
1/14/10 15:00	1/15/10 13:30	5.5	53	0.01	0.00	31.6		
1/15/10 14:00	1/18/10 12:35	6.9	-49	0.00	0.00	49.0		
1/18/10 14:00	1/19/10 14:54	5.0	234	0.02	0.00	54.7		
1/19/10 16:10	1/20/10 10:30	6.2	54	0.01	0.00	58.2	<0.02	<0.05
1/20/10 11:10	1/21/10 13:15	6.9	30	0.01	0.00	63.4		
1/21/10 16:00	1/22/10 13:04	6.4	30	0.07	0.01	67.6		
1/22/10 16:00	1/25/10 14:45	6.8	85	0.36	0.04	81.1		
1/25/10 15:15	1/26/10 14:30	8.5	91	0.70	0.07	85.5		
1/26/10 16:30	1/27/10 9:00	6.8	30	2.0	0.17	88.9	0.53	0.56
1/27/10 9:17	1/28/10 15:10	8.3	32	3.0	0.26	99.4		
1/28/10 16:45	1/29/10 14:20	8.2	21	4.4	0.38	107.3		
1/29/10 15:33	2/1/10 13:30	7.2	122	6.4	0.55	124.0		
2/1/10 14:30	2/2/10 10:05	7.5	145	7.2	0.62	128.5		
2/2/10 12:10	2/3/10 14:45	7.8	27	6.8	0.59	135.1		
2/3/10 16:20	2/4/10 16:30	7.1	-33	9.8	0.84	139.7	6.8	6.72
2/4/10 17:45	2/5/10 10:45	6.9	20	7.4	0.54	145.4		
2/5/10 14:30	2/8/10 13:30	8.1	27	5.8	0.43	173.6		
2/8/10 15:00	2/9/10 13:18	6.7	-17	7.4	0.54	180.6		
2/9/10 15:00	2/11/10 13:25	7.1	121	9.8	0.88	184.0		
2/11/10 15:24	2/12/10 14:50	7.7	29	8.8	0.79	189.7	10.1	11.2
2/12/10 16:50	2/13/10 9:20							
2/13/10 9:52	2/14/10 12:05			12.4	1.11	186.3		
2/14/10 12:22	2/15/10 8:50	7.6	60	2.8	0.25	204.9		
2/15/10 11:35	2/16/10 11:10	7.1	85	6.0	0.54	217.6		
2/16/10 14:37	2/17/10 8:32	9.2	73	5.8	0.53	227.5	12.6	11.6
2/17/10 9:00	2/18/10 8:25	7.3	54	6.2	0.56	236.0		
2/18/10 13:53	2/19/10 8:50	7.1	104	7.0	0.64	236.1		
2/19/10 11:00	2/20/10 10:15							
2/20/10 10:35	2/21/10 11:25			10.8	0.98	236.6		
2/21/10 12:15	2/22/10 9:34	6.5	113	5.6	0.51	249.2		
2/22/10 13:30	2/23/10 16:30	6.9	55	11.4	1.04	248.0		
2/23/10 17:55	2/24/10 10:15	5.7	210	11.8	1.18	244.9	10.7	10.7
2/24/10 10:57	2/25/10 8:20	7.1	84	6.0	0.6	254.0		
		6.8						
							8.146	8.156

Attachment 3

Shield Alloy Post-Treatability Batch Tests Performed on Unamended mZVI Control Columns for Soils from Shallow and Deep Plume Zones

Hexavalent Chromium Reduction Tests Using 550 mg/l Hexavalent Chromium Solution

Testing was performed on soils obtained from the top and bottom of unamended control columns used for mZVI treatability tests of soils from the shallow and deep plume zones. Soils were recovered at the conclusion of the mZVI treatability study from the unamended column and placed in batch reactors with a aqueous solution containing 550 mg/l of hexavalent chromium and monitored for 21 days. Reductions in hexavalent chromium concentrations and mass by native iron in shallow and deep soils are summarized below.

100 g soil + 100 mL 550 mg/L Cr6+ solution						Soil Extract			
Control ID	Date	Day	Hach Hex Cr mg/L	Soil Hex Cr mg/kg	Soil Total Cr mg/kg	Hach Hex Cr mg/L	pH SU	ORP mV	
Control column (Shallow Soil & IW2 GW)									
Inlet (bottom) section of column									
1I	3/24/2010	1	480	2.44	10.7	0.37	7.3	135	
	3/26/2010	3	400						
	3/29/2010	6	420						
	3/31/2010	8	440						
	4/6/2010	14	330						
	4/13/2010	21	410						
total Cr(VI) mass removed from solution post column test = (starting concentration - ending concentrations) * reactor GW								14 mg	
							% Reduction =	25%	
Exit (top) section of column									
1E	3/24/2010	1	480	2.31	15.0	0.24	8.7	65	
	3/26/2010	3	320						
	3/29/2010	6	360						
	3/31/2010	8	480						
	4/6/2010	14	420						
	4/13/2010	21	350						
total Cr(VI) mass removed from solution post column test = (starting concentration - ending concentrations) * reactor GW								20 mg	
							% Reduction =	36%	
Control column (Deep soil & SC2Dr GW)									
Inlet (bottom) section of column									
4I	3/24/2010	1	530	<1.24	112	0.20	6.1	161	
	3/26/2010	3	360						
	3/29/2010	6	380						
	3/31/2010	8	370						
	4/6/2010	14	330						
	4/13/2010	21	330						
total Cr(VI) mass removed from solution post column test = (starting concentration - ending concentrations) * reactor GW								22 mg	
							% Reduction =	40%	
Exit (top) section column									
4E	3/24/2010	1	520	<1.21	101	0.35	6.5	89	
	3/26/2010	3	350						
	3/29/2010	6	430						
	3/31/2010	8	630						
	4/6/2010	14	340						
	4/13/2010	21	440						
total Cr(VI) mass removed from solution post column test = (starting concentration - ending concentrations) * reactor GW								11 mg	
							% Reduction =	20%	

Batch Tests of Control Column Soils Post Treatability Testing
Cumulative Cr6+ Removal
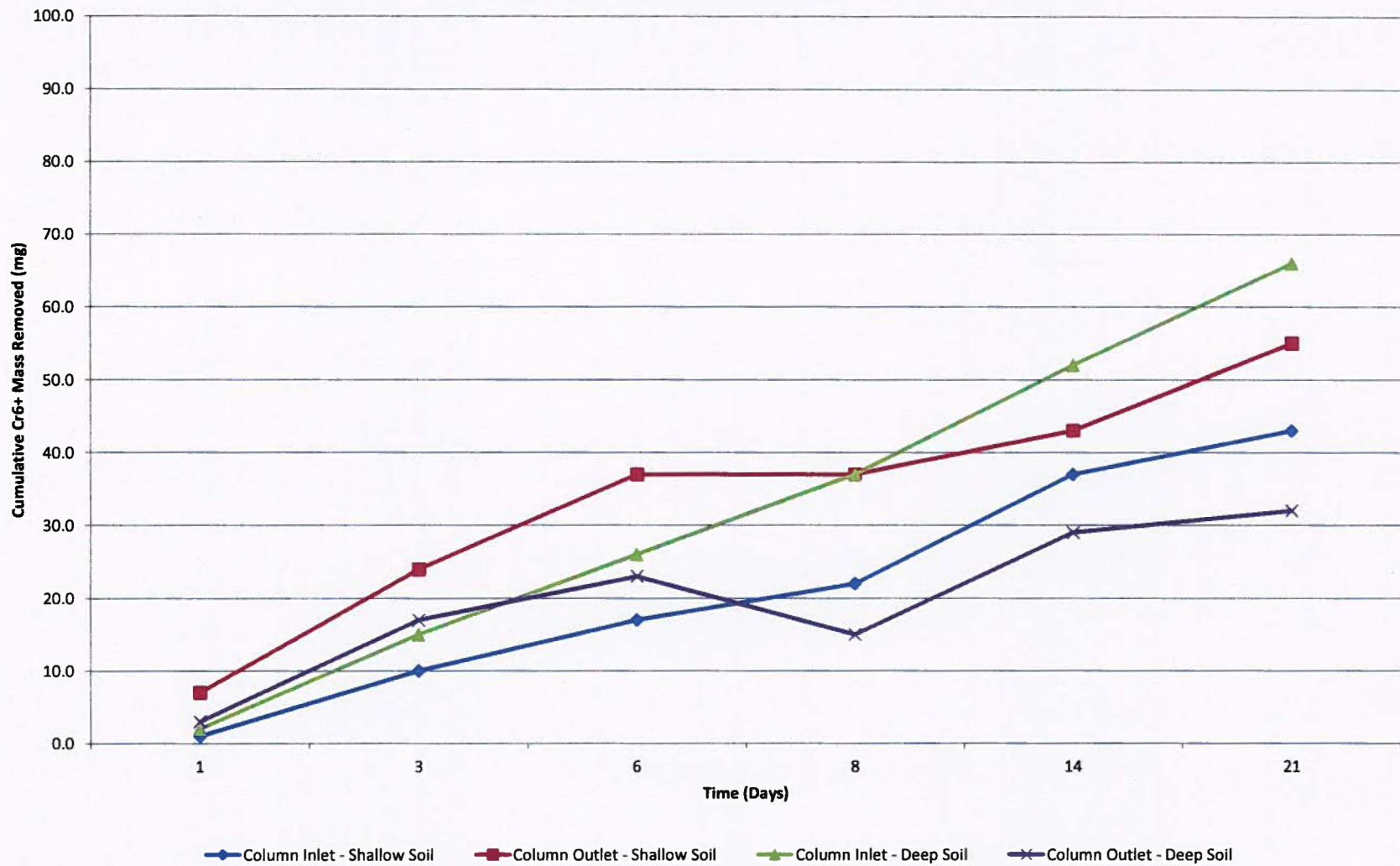
ATTACHMENT 4
SOIL-CO-LOCATED GROUNDWATER ANALYTICAL DATA
CHROMIUM REDUCTION DATA FOR CONTROL SAMPLES
FROM TREATABILITY STUDIES

Groundwater Monitoring Location	Monitored Interval (ft bgs)	Total Chromium (mg/l)	Hexavalent Chromium (mg/l)	Soil Sampling Location	Sample Depth (ft bgs)	Total Chromium (mg/kg)	Sorption Coefficient, K_d - Cr^1 (l/kg)	Retardation Factor[2] (dimensionless)
				Lower Plume				
VP-3	90 to 95	0.0289	**0.005**	VP-3	90 to 95	3.4	NC	NC
VP-1	90 to 95	0.0143	**0.005**	VP-1	90 to 95	4.9	NC	NC
VP-1	104 to 109	0.18	0.048	VP-1	100 to 105	4.9	102	409
VP-3	110 to 115	0.163	0.078	VP-3	110 to 115	6	77	309
SC-42D	110 to 120	**0.005**	0.01	SC-42D	105 to 125	6.3	630	2521
IW-2 (P80-90) (1/10)	80 to 90	21.3	21.5	STSB-1	80 to 90	7.3	0.3	2.4
IW-2 (P110-120)(1/10)	110 to 120	0.011	**0.005**	STSB-1	110 to 120	11.2	NC	NC
SC-41D	110 to 120	0.0408	0.013	SC-41D	110 to 120	11.8	908	3632
SC-2DR	106 to 116	19.77	24.6	TS-SC2DR	106.5 to 107	23.5	1.0	4.8
IW-2 (P95-105) (1/10)	95 to 105	12.5	12.9	STSB-1	90 to 110	24.4	1.9	8.6
SC-2DR (10/09)	106 to 116	12	11.6	STSB-1	110 to 120	24.4	2.1	9.4
W9 (10/09)	110 to 130	4.35	4.2	STSB-2	105 to 130	32.4	7.7	32
						Geomean =	15	69
				Upper Plume				
VP-3	55 to 60	0.0972	**0.005**	VP-3	55 to 60	2.9	NC	NC
SC-38I	45 to 55	0.0499	0.045	SC-41D	45 to 65	3	67	301
SC-2I	40 to 70	2.28	2.6	SC-2I	45 to 65	3.05	1.2	6.3
IW-1	32 to 62	**0.005**	0.016	SC-42D	45 to 65	3.53	221	994
VP-3	75 to 80	0.0954	0.022	VP-3	75 to 80	4.5	205	921
VP-3	20 to 25	**0.005**	**0.005**	VP-3	20 to 25	5.2	NC	NC
Layne (10/09)	43 to 48	1.09	0.91	STSB-2	35 to 50	8.4	9.2	43
Well B (10/09)	36 to 46	0.205	**0.005**	STSB-2	35 to 50	8.4	NC	NC
IW-2 (10/09)	40 to 70	4.81	4.4	STSB-1	40 to 70	10.2	2.3	11
VP-3	35 to 40	1.74	**0.005**	VP-3	35 to 40	14.3	NC	NC
						Geomean =	21	97

Notes:

Detection limit for chromium is 0.005 mg/l

NC = Not calculated since chromium not detected in groundwater at colocated location. Detection limit shown in bold.

1 = sorption coeffecint is defined as the concentration of total chromium in the soils divided by the concentration of hexavalent chromium in co-located groundwater sample.

2 = Retardation factor, $R = 1 + (Kd*\rho_b)/n$, where ρ_b is the soil bulk density and n is the total soil porosity.

Porosity of aquifer sands was calculated to be 0.4 during treatability testing. The dry bulk density of sand in upper and lower aquifers was estimated to be 1.6 kg/l and 1.8 kg/l ((between 100 and 110 pounds per cubic foot based upon data from Walton, 1991.

Principles of Groundwater Engineering. Lewis Publishers, Boca Raton, Fl.

Concentration of Total Chromium in Soil and Groundwater - Upper Plume
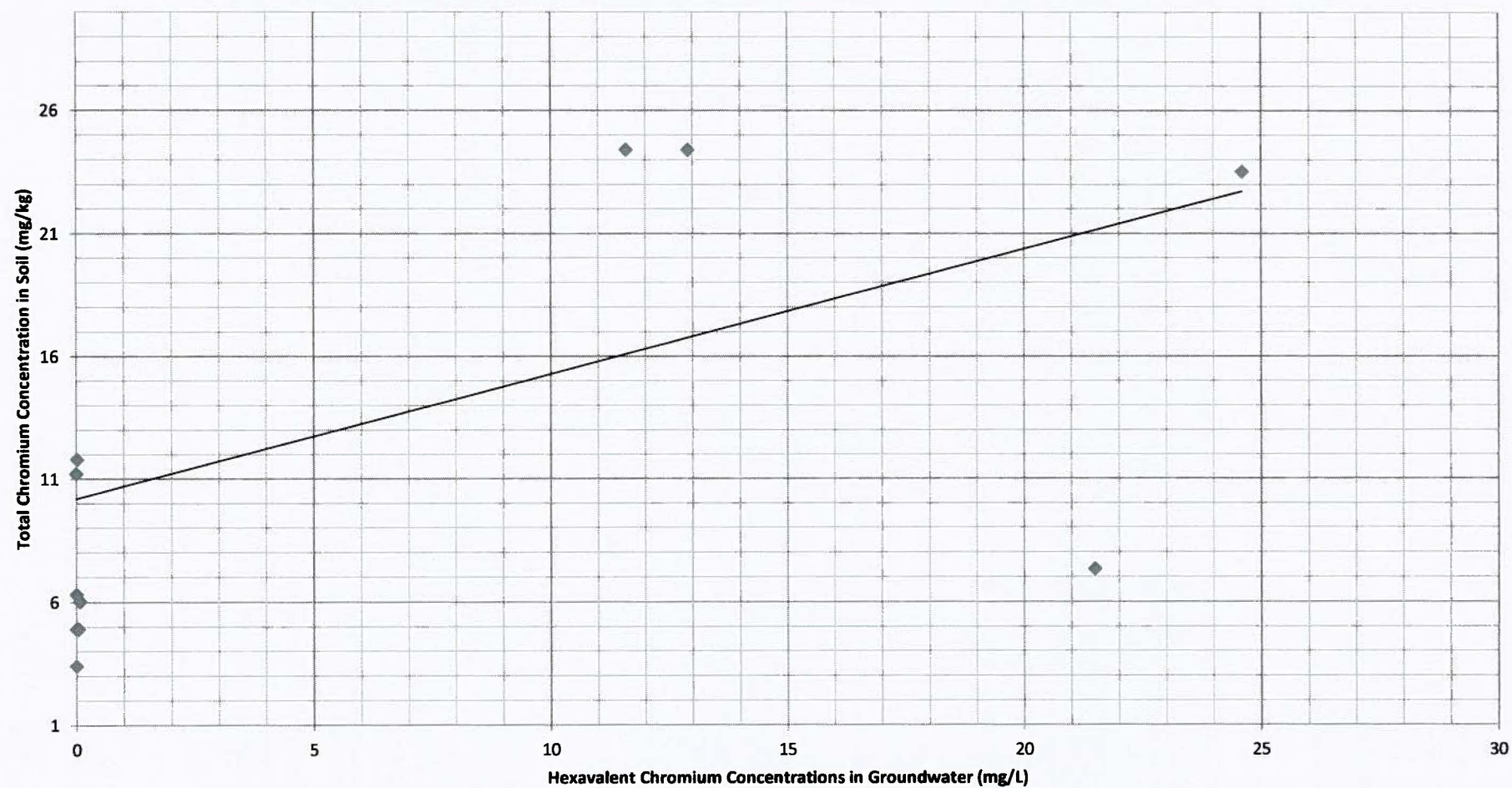
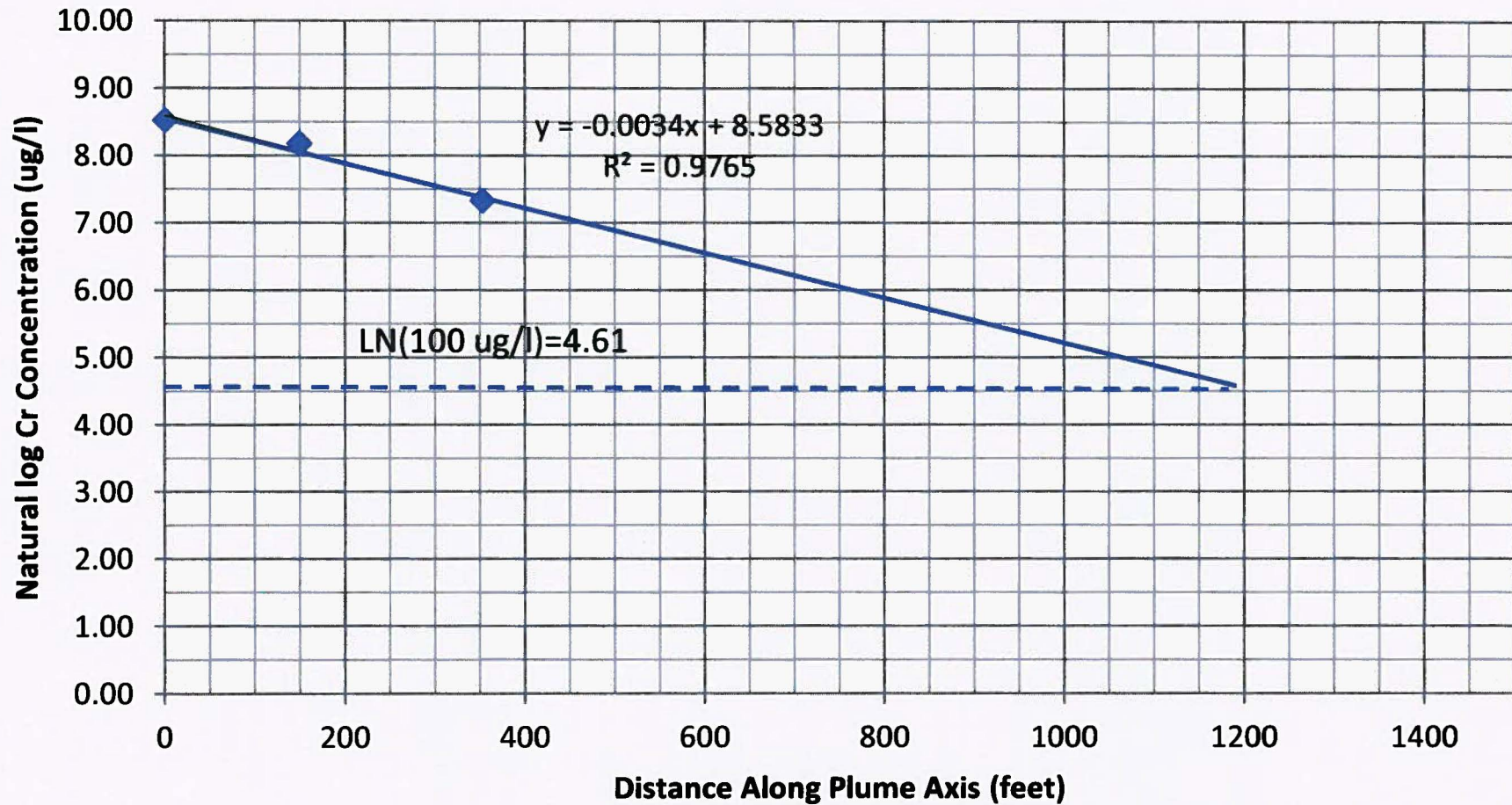Concentration of Total Chromium in Soil and Groundwater - Lower Plume
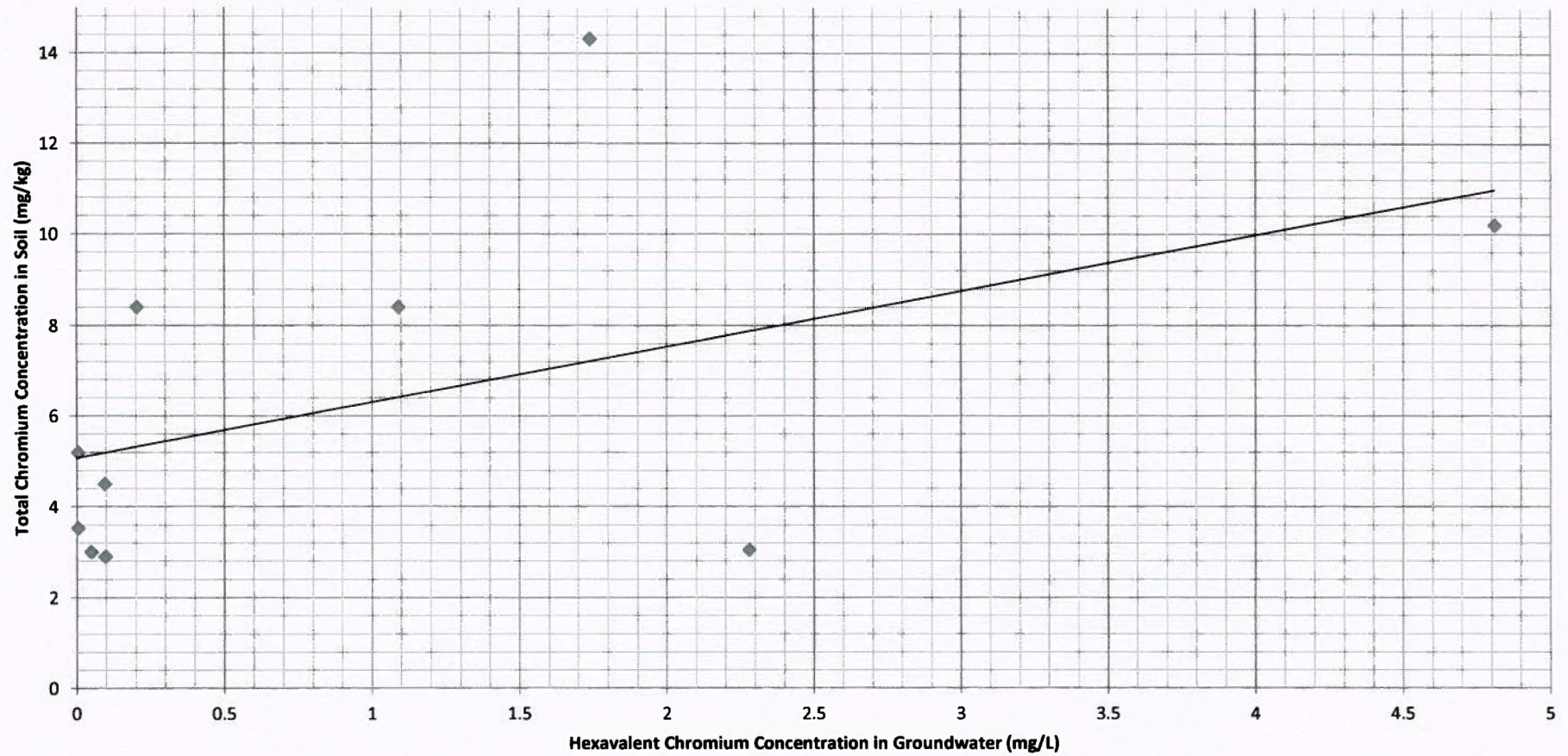
ATTACHMENT 5
DECLINE IN CHROMIUM CONCENTRATIONS ALONG GROUNDWATER FLOWPATHS
AND BULK ATTENUATION RATE – HALF LIFE CALCULATIONS

Attachment 5
Declining Concentration Data
Along Groundwater Flow Path
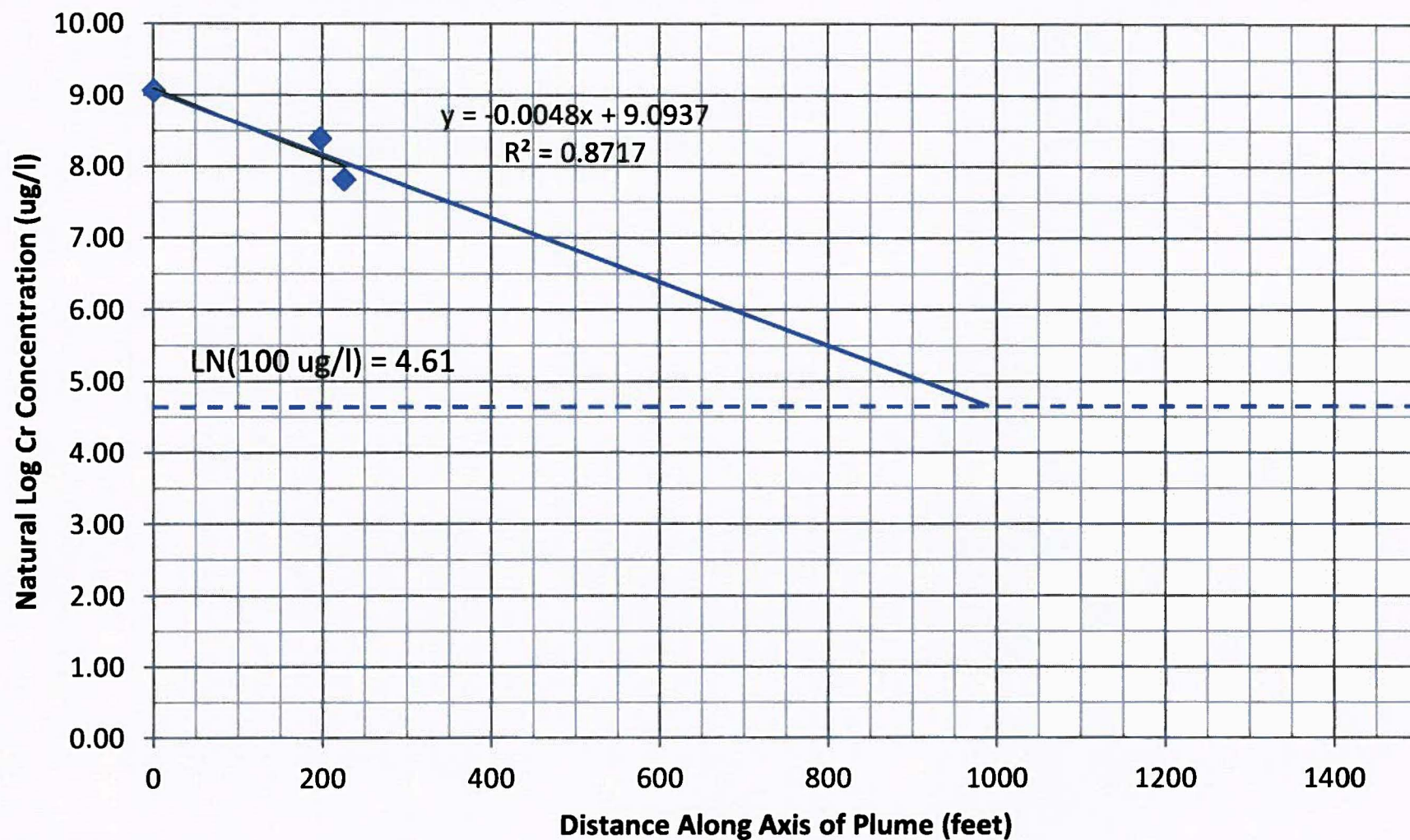## Shield Alloy Site
Newfields, New Jersey

Well Location	Distance Along Flowpath (feet)	Total Chromium Concentration (ug/l)	LN(conc) (ug/l)
Lower Plume			
L7-C1	1	12100	9.40
LPW-8	113	9640	9.17
L8-A2	212	6630	8.80
L7-D2	1	11600	9.36
L8-C2	198	9040	9.11
L9-B2	362	6870	8.83
Upper Plume			
U7-B	1	8310	9.03
U8-B	198	4690	8.45
SC-21	226	2470	7.81
U6-A	1	5000	8.52
U-7A	150	3550	8.17
U8-E	353	1510	7.32

Natural Log Cr vs Distance - U6-A to U8-E

$y = -0.0034x + 8.5833$

$R^2 = 0.9765$

LN(100 ug/l)=4.61

Natural log Cr Concentration (ug/l)

Distance Along Plume Axis (feet)

Natural Log Cr vs Distance - U7-B to SC-21

$y = -0.0048x + 9.0937$

$R^2 = 0.8717$

LN(100 ug/l) = 4.61

Natural Log Cr Concentration (ug/l)

Distance Along Axis of Plume (feet)

Natural Log Cr vs Distance - L7-C1 to L8-A2

$y = -0.0028x + 9.4324$
$R^2 = 0.9696$
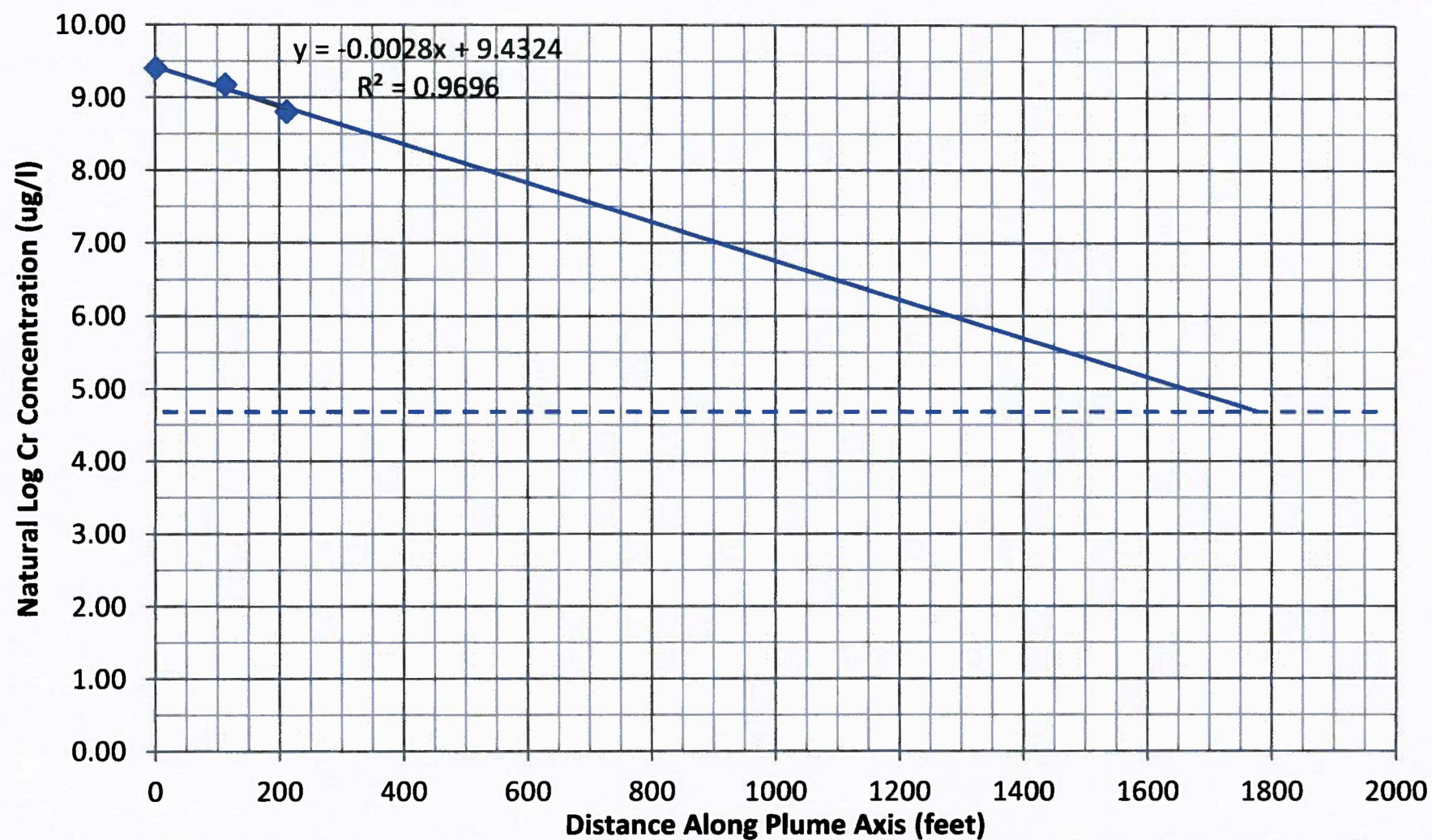
Natural Log Cr vs Distance - L7-D2 to L9-B2
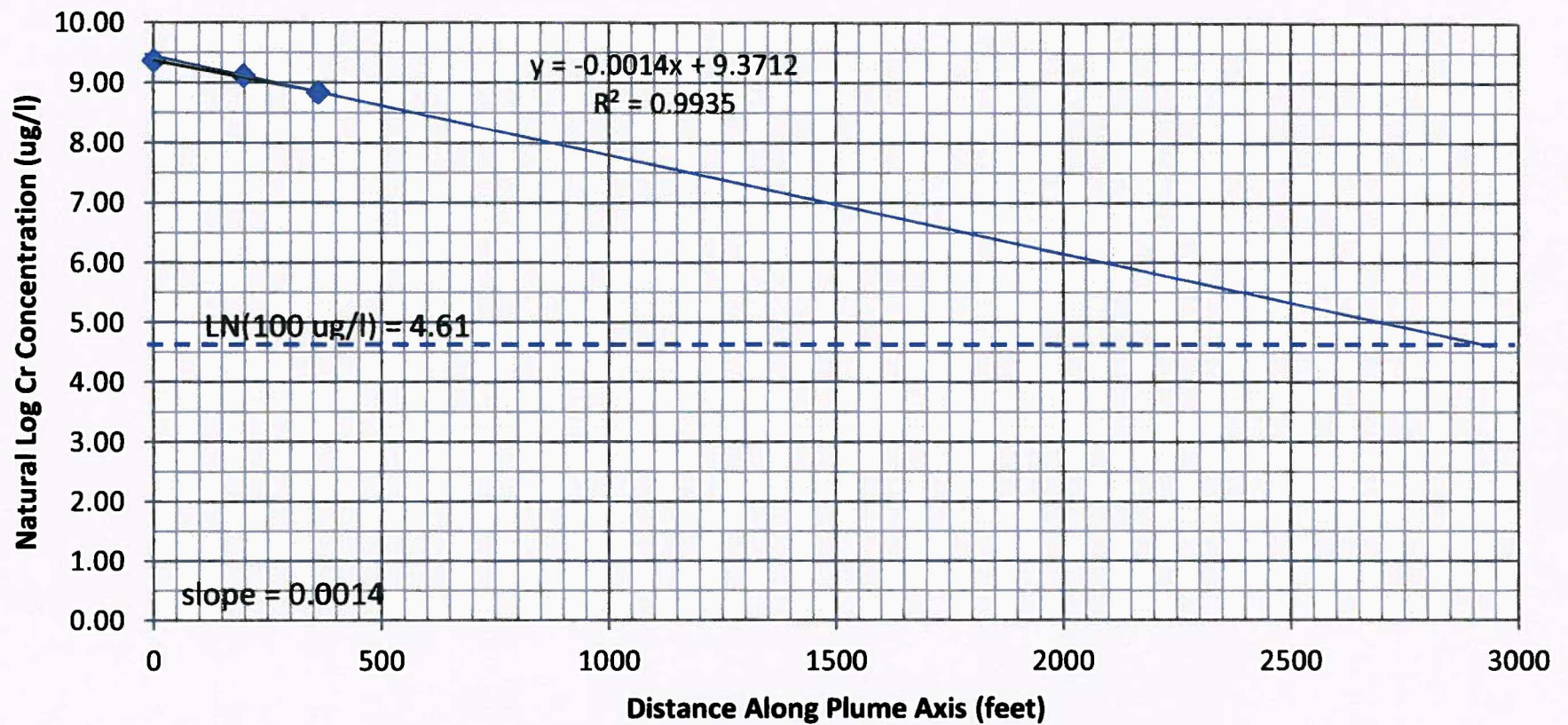
Statement of Problem:

Calculate Bulk Attenuation Rate Constants to Support Evaluation of Natural Attenuation

Approach:

Method described in "*Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies* " (EPA, 2002).

1. Plot natural log of concentration versus distance along flowpath.
2. Perform linear regression of the data to calculate slope of natural log of concentration versus distance (refer to plots).
3. Multiply the slope calculated by the regression analysis by the groundwater seepage velocity V_{gw} to obtain bulk attenuation factor (rate constant), λ.
4. Calculate the half life = $LN(2)/\lambda$.

Calculation of Groundwater seepage velocities

$$V_{gw} = (K * i)/n_e$$

Where: V_{gw} = Groundwater seepage velocity, Length/Time;
K = Horizontal hydraulic conductivity, Length/Time;
i = hydraulic gradient (dimensionless); and
n_e = effective porosity (dimensionless).

Upper Aquifer

	K (ft/day)	i	n_e	V_{gw} (ft/day)	(ft/yr)
Low	250	0.0017	0.35	1.21	443
High	706	0.0017	0.25	4.80	1752
Geomean	353	0.0017	0.3	2.00	730

Lower Aquifer

	K	i	n_e	V_{gw}	
	(ft/day)			(ft/day)	(ft/yr)
Low	64	0.0016	0.3	0.34	125
High	137	0.0016	0.25	0.88	320
Geomean	92	0.0016	0.2	0.74	269

Notes:

1. Hydraulic conductivity estimated from transmissivities reported by Dan Raviv Associates for pumping tests performed in the upper and lower aquifers and saturated thickesses at observation well locations.
2. Horizontal hydraulic gradient based upon equipotential contours developed from water level data measured during in April 2012.
3. Effective porosity based upon literature values corresponding to the predominant soil type for the upper and lower aquifers, respectively. Walton, 1991. Principles of Groundwater Engineering. Lewis Publishing, Boca Raton, Fl.

Bulk Attenuation Rate/Half-Life Calculations

Upper Aquifer

Transect Location	Slope of LN(concentration) Vs. Distance	Groundwater Seepage Velocity (ft/day)	Attenuation Factor (day^{-1})	1/2-Life (years)
U6-A to U8-E	0.0034	1.21	0.004	0.5
U6-A to U8-E	0.0034	4.8	0.016	0.1
U7-B to SC-2I	0.0048	1.21	0.006	0.3
U7-B to SC-2I	0.0048	4.8	0.023	0.1

Lower Aquifer

Transect Location	Slope of LN(concentration) Vs. Distance	Groundwater Seepage Velocity (ft/day)	Attenuation Factor (day^{-1})	1/2-Life (years)
L7-C1 to L8-A2	0.0028	0.34	0.0010	2.0
L7-C1 to L8-A2	0.0028	0.88	0.0025	0.8
L7-D2 to L9-B2	0.0014	0.34	0.0005	4.0
L7-D2 to L9-B2	0.0014	0.88	0.0012	1.5

Note: See figures showing LN(concentration) vs. Distance for each transect for slopes.

ATTACHMENT 6
ATTENUATION CAPACITY CALCULATIONS

Statement of Problem:

Estimate the attenuation capacity of aquifer soils within the upper and lower chromium plumes.

Approach:

An estimate of the attenuation capacity of aquifer soils can be made using data from un-amended column tests and batch tests performed on the columns after completing the treatability study as shown below.

Upper Chromium Plume

Bulk Chromium Attenuation capacity = $(C_{cs}/M_{s\,cs} + C_{bt}/M_{s\,bt})$ Equation 1

Where: C_{cs} = Chromium attenuated by reductants, precipitation, and sorption in soil column study, = 24 milligrams (mg);

          $M_{s\,cs}$ = Mass of soil in unamended soil column constructed using soil from upper plume, 1.855 kilograms (Kg);

          C_{bt} = Mass of chromium removed from soil during batch tests performed on soils from column after

             column treatability study = 17 mg on average;

          $M_{s\,bt}$ = Mass of soil used in batch test reactors = 0.1 Kg.

Based upon these data, the attenuation capacity of soil from the upper aquifer zone was estimated to be:

       24 mg/1.855 kg soil + 17 mg/0.1 kg soil = 183 mg chromium/Kg of soil

Assuming that this attenuation capacity is representative of soils in the shallow plume and assuming on average that the dry weight of the medium to coarse sand in the upper aquifer is approximately 100 pounds per cubic foot (45 kg per cubic foot) which is consistent with data presented in the literature (Walton ,1991), one cubic foot of soil should be able to attenuate:

       183 mg chromium/Kg soil * 45 Kg/ft^3 * 1 gram/1000 mg = 8.2 grams of chromium per cubic foot of soil.

The maximum concentration of chromium detected in groundwater in wells screened in the shallow plume between the Facility and Farm Parcel injection area during sampling performed in October 2012 was 490µg/l at RW-6S. Using this concentration, the total mass of dissolved chromium in a cubic foot of soil from the upper aquifer can be calculated as follows:

       $M_{cr} = 1\ ft^3 * n * C_{aq} *\ 28.32\ liters/ft^3 * 1\ gram/1,000\ mg$ Equation 2

Where: Mcr = Mass of dissolved chromium contained in the pore space of one cubic foot of soil, grams;

          n = porosity of soil = 0.4 (calculated for soils usded during the TRC treatability study).

          C_{aq} = dissolved concentration of chromium in groundwater = 0.49 milligrams per liter (mg/l).

Based upon these data, a conservative estimate of dissolved chromium contained in a cubic foot of soil in the upper plume at the Car Wash Property is:

       $M_{cr} = 1\ ft^3 * 0.4 * 28.32\ liters/ft^3 * 0.49\ mg/l * 1\ gram/1,000\ mg = 0.006$ grams chromium per cubic foot.

This mass (0.006 grams per cubic foot) is significantly less than the attenuation capacity for soils in the upper plume (8 grams per cubic foot).

It is recognized that residual dissolved chromium is present in groundwater between well RW-6S and the Facility Property. While at least a portion of this chromium will be attenuated in soil upgradient of RW-6S, the following calculation was performed to conservatively assess the capacity of soils in the area between the Facility and Farm Parcel Injection Areas to attenuate dissolved chromium .

$$M = L * A * n * C_{aq} * CF_{volume} * CF_{mass} \qquad \text{Equation 3}$$

Where: M = Mass of dissolved chromium contained in a one square foot flow tube extending from the Facility to well RW-6S, grams

L = Distance between the CPS treatment area at Facility and well RW-6S = 775 feet

A = Cross sectional area of flow tube - assume 1 square foot based upon predominant horizontal flow

n = Porosity (0.4 calculated for soils used in the TRC treatability study)

C_{aq} = Concentration of chromium in groundwater, use 0.49 mmg/l based upon concentration in RW-6S Octobe 2012

CF_{volume} = Conversion factor to convert cubic feet to liters - 28.32 liters/ft^3

CF_{mass} = Conversion factor to convert milligrams to grams - 1 gram/1000 milligrams

M = 775 feet * 1 ft^2 * 28.32 liters/ft^3 * 0.4 * 0.49 mg/l * 1 gram/1000 mg = 4.3 grams in 775 cubic feet of soil which is approximately half of the attenuationcapacity of 8.2 grams per cubic foot calculated for the soils in the upper plume.

These data indicate that the upper aquifer has adequate capacity to attenuate dissolved chromium remaining in the area between the Facility and Farm Parcel Injection Areas.

Lower Chromium Plume

Using the same equations as for the upper plume;

Bulk Chromium Attenuation capacity = $(C_{cs}/M_{s\,cs} + C_{bt}/M_{s\,bt})$

Where: C_{cs} = Chromium attenuated by reductants, precipitation, and sorption in soil column study, = 224 milligrams (mg) based upon the difference between the mass throughput of chromium in the influent and effluent of the un-amended column for the deep zone - see Attachment 4

$M_{s\,cs}$ = Mass of soil in unamended soil column constructed using soil from upper plume, 1.860 kilograms (Kg);

C_{bt} = Mass of chromium removed from soil during batch tests performed on soils from column after column treatability study = 16.5 mg on average;

$M_{s\,bt}$ = Mass of soil used in batch test reactors = 0.1 Kg.

Based upon these data, the attenuation capacity of soil from the lower aquifer zone was estimated to be:

224 mg/1.860 Kg soil + 16.5 mg/0.1 Kg soil = 285 milligrams chromium attenuated per kilogram of soil

Assuming that this attenuation capacity is representative of soils in the deep plume and assuming on average that the dry weight of the medium sand in the upper aquifer is approximately 110 pounds per cubic foot (50 kilograms per cubic foot) which is consistent with data presented in the literature (Walton ,1991), one cubic foot of soil should be able to attenuate:

285 mg chromium/Kg soil * 50 Kg/ft^3 * 1 gram/1000 mg = 14.3 grams of chromium.

The maximum concentration of chromium detected in groundwater in wells screened in the deep plume between the Facility and Farm Parcel injection areas during sampling performed in October 2012 was 2,140µg/l at RW-6D. Using this concentration, the total mass of dissolved chromium in a cubic foot of soil, a total porosity of 0.4 quantified during the treatability study performed by TRC according to equation 2 would be:

1 ft^3 * 0.4 * 28.32 liters/ft^3 * 2.14 mg/l * 1 gram/1,000 milligrams = 0.024 grams chromium per cubic foot of soil.

This estimate is significantly lower than the attenuation capacity for soils in the lower plume (14.3 grams per cubic foot) estimated from the column test data.

It is recognized that residual dissolved chromium is present in groundwater between well RW-6D and the Facility Property. While at least a portion of this chromium will be attenuated in soil upgradient of RW-6D, the following calculation was performed to conservatively assess the capacity of soils at RW-6S to attenuate dissolved chromium upgradient of this location.

$$M = L * A * n * C_{aq} * CF_{volume} * CF_{mass}$$

Where: M = Mass of dissolved chromium contained in a one square foot flow tube extending from the Facility to well RW-6D, grams

L = Distance between the CPS treatment area at Facility and well RW-6D = 775 feet

A = Cross sectional area of flow tube - assume 1 square foot based upon predominant horizontal flow

n = Porosity (0.4 calculated during the TRC treatability study)

C_{aq} = Concentration of chromium in groundwater, assume 1.49 milligrams per liter based upon the average concentration of chromium detected in wells A, W-9 located immediately downgradient of the CPS injection area at the Facility and RW-6D.

CF_{volume} = Conversion factor to convert cubic feet to liters - 28.32 liters/ft^3

CF_{mass} = Conversion factor to convert milligrams to grams - 1 gram/1000 milligrams

M = 775 feet * 1 ft^2 * 28.32 liters/ft^3 * 0.4 * 1.49 mg/l * 1 gram/1000 mg = 13 grams in 775 cubic feet of soil which is slightly less than the attenuationcapacity calculated for the soils in the deeper plume of 14 grams per cubic foot of soil.

The above calculations indicate that sufficient attenuation capacity exists to address dissolved chromium remaining in the shallow and deep aquifers between the Facility and Farm Parcel CPS injection areas. It is also noted that in addition to attenuation by native iron, any chromium that is migrates into the CPS injection area upgradient of the Farm Parcel will be immobilized by residual CPS in the aquifer which will enhance natural attenuation.

Statement of Problem:

Evaluate the attenuation capacity of ferrous iron present in site soils using data from mineralogic analysis
obtained during treatability studies performed on Site Soils and stoichiometry of chromium reduction by ferrous iron.

Analysis:

Mineralogic analysis of soil from STSB-1 (at the Farm Parcel) used for the Column Treatabiliity Study for the deep soil indicated
the presence of the ferrous iron mineral pyrite (FeS_2). Corundum was addted to the sample to determine amorphous content and
comprised 21.3 percent of the sample; however, the soil did not contain any amorphous content. The mineralogic analysis indicated
that the soil from the deepaquifer was comprised of the following, adjusted to exclude non-native corundum.

Mineral	% Mass of Sample	% Mass In Soil
Quartz, SiO_2	78.9	99.2
Corundum, Al_2O_3	21.3	0
Pyrite, FeS_2	0.6	0.8
Total	100	100

Mineralogical analysis of a sample of deep soil obtained from MWH-4 on the Facility property that was analyzed prior to use in the
treatability study performed by Stevens in 2007 was also found to contain pyrite at 4.2 percent of the soil mass.

Given that 1 weight percent = 10,000 mg/kg, the concentration of pyrite in the soils from the deep aquifer zone range from
8,000 mg/kg to 42,000 mg/kg.

The stoichometric equation for pyrite shown below indicates that one mole pyrite is comprised of one mole of
ferrous iron (55.85 grams) and 2 molesof Sulfur (64.12 grams).

$$Fe^{2+} + 2S => FeS_2$$
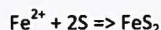
Based upon these data, pyrite consists of about 47 percent ferrous iron as shown in the following calculation:

Molecular weight of FeS_2 = 55.85 grams/mole Fe + (2 moles S * 32.06 grams/mole) = 120 grams/mole

Molecular weight of one mole iron/Molecular weight of pyrite = 55.85 grams/mole/120 grams/mole * 100 = 47 %

Based upon the mass of pyrite identified during mineralogic analysis of soils during the treatability study, the amount of
ferrous iron present in the soil samples from the deep aquifer analyzed as part of the treatability test was calculated to be:

Mass Ferrous iron = % mass of pyrite in soil * 10,000 mg per kilogram/1 % * percent iron/mole pyrite

Sample Location	% Pyrite In Soil	Converion Factor (mg per Kg/%)	Mass Fraction of Fe^{2+} in Pyrite	mg of Fe^{2+} per Kilogram of Soil
STSB-1	0.8	10,000	0.47	3,760
MWH-4	4.2	10,000	0.47	19,740

Ferrous iron in the pyrite will act as a reductant (EPA, 1994).

The stoichiometric equation representing reduction of hexavalent chromium to chromium hydroxide precipitate
by ferrous iron is as follows:
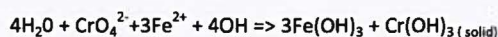
$$4H_2O + CrO_4^{2-} + 3Fe^{2+} + 4OH => 3Fe(OH)_3 + Cr(OH)_{3\,(solid)}$$

This equation suggests that 3 moles of ferrous iron are required to reduce 1 mole of hexavalent chromium, which equates to 3.2 grams of ferrous iron to reduce (attenuate) 1 gram of hexavalent chromium. However, a study performed by the United States Department of Energy (1995) found that approximately 9 moles of ferrous iron was needed to complete the reaction for the soils that were evaluated in that study. The greater amounts of ferrous iron was likely due to consumption of ferrous iron in competing reactions.

Conservative estimates of dissolved chromium mass contained in a cubic foot of soil in the lower aquifers between the Facility and Farm Parcel Injection Areas was previously calculated in Attachment 6. This mass estimate summarized below as mass of chromium per kilogram of soil based upon the estimated dry weight of the soils.

	Grams Dissolved Cr in Cubic Foot of Soil	Estimated Dry Mass of Soil (kg/ft^3)	Mass Chromium per Kilogram Soil	
			(g/kg)	(mg/kg)
Lower Aquifer	0.024	50	0.00048	0.48

Based upon the stoichiometric requirements for ferrous iron, the amount of ferrous iron required to reduce the dissolved chromium contained in one kilogram of soil in the lower aquifers would be approximately 0.002 grams as summarized below:

	Mass Fe^{2+} Required to Reduce 1 gram Hexavalent Chromium (grams)	Dissolved Mass Chromium In Kilogram Soil $(grams)^1$	Mass Fe^{2+} Required to Reduce Dissolved Hexavalent Chromium in Kg of Soil (grams)	Total Fe^{2+} in Soil (grams/Kg)	Safety Factor Fe^{2+} In Soil/ Fe2+ Needed to Reduce Chromium
Lower Aquifer (based upon Ferrous Iron Content from STSB-1)	3.2	0.00048	0.0015	3.76	2,448
Lower Aquifer (based upon Ferrous Iron Content from MWH-4)	3.2	0.00048	0.0015	19.7	12,826

(1) Assume all dissolved Chromium is in hexavalent form

The calculations show that the soils from the deep aquifer used for the treatability studies contain between 2,400 and 12,800 more ferrous iron than stoichiometrically needed to reduce conservative estimates of dissolved chromium in the in the lower plume. The excess ferrous iron is significantly greater than competing demands for ferrous iron by other geochemical reactions at other sites and appears to be sufficient to attenuate dissolved chromium in the aquifer between the Facility and Farm Parcel Injection Areas.